Final Report

Munitions Classification Library

ESTCP Project MR-201424

April 2016

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ESTCP

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
04/04/2016

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
August 2014 - August 2015

4. TITLE AND SUBTITLE
MUNITIONS CLASSIFICATION LIBRARY

5a. CONTRACT NUMBER
W912HQ-14-C-0029

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER
MR-201424

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program Program Office
4800 Mark Center Drive
Suite 17D03
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Ninety percent of excavation costs on most UXO/MEC projects are related to removing scrap metal that does not represent an explosive hazard. Advanced time-domain electromagnetic induction (TEM) systems and response modeling software – both developed under SERDP and ESCTP research efforts – offer to significantly reduce the quantity of scrap metal that needs to be removed during a MEC cleanup project.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Mr. Craig Murray
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	62	303-764-8868

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ACRONYMS

Abbreviation	Definition
AOL	Advanced Ordnance Locator
CRREL	Cold Regions Research and Engineering Laboratory
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
HDF	Hierarchical Data Format
ISO40	Industry Standard Object (Schedule 40)
ISO80	Industry Standard Object (Schedule 80)
MEC	Munitions and Explosives of Concern
MM	MetalMapper
MPV	Man-Portable Vector
MTADS	Multi-sensor Towed Array Detection System
NAVSEA	Naval Sea Systems Command
NRL	Naval Research Laboratory
OD	Outer Diameter
PEDEMIS	PortablE Decoupled ElectroMagnetic Induction Sensor
MPEDEMIS	Modified PEDEMIS
PVC	Poly Vinyl Chloride
RX	Receiver
SERDP	Strategic Environmental Research and Development Program
SNR	Signal-to-Noise Ratio
SOP	Standard Operating Procedure
TEM	Time-domain ElectroMagnetic
TEMTADS	Time-domain ElectroMagnetic mTADS
TX	Transmitter
USACE	US Army Corps of Engineers
UXO	Unexploded Ordnance
WP	White Phosphorus

1.0 INTRODUCTION

Ninety percent of excavation costs on most UXO/MEC projects are related to removing scrap metal that does not represent an explosive hazard. Advanced time-domain electromagnetic induction (TEM) systems and response modeling software – both developed under SERDP and ESCTP research efforts – offer to significantly reduce the quantity of scrap metal that needs to be removed during a MEC cleanup project. This generally comes about by using the system response model to extract parameters characteristic of the metal item being measured by the sensor and comparing these to a library of munitions parameters. If a good match ensues, the item is classified as munitions and flagged for excavation. Otherwise, the item is either classified as clutter and deemed safe to leave in the ground or flagged for further scrutinization.

1.1 BACKGROUND

With ESTCP support, Geometrics has already commercialized one advanced TEM system called the MetalMapper (MM) [1] and is close to releasing another based on the TEMTADS 2x2 [2], with possible future internal plans to include even more advanced TEM systems, such as a handheld version based on the MPV [3]. Historically, all these systems were developed by Dave George of G&G Sciences, Inc (through NAVSEA, SERDP and ESTCP support) with various alliances (CRREL, NRL, Geometrics, etc.) and are all based on similar hardware and electronics components, but in differing quantities and configuration. Using a standardized modular approach, Geometrics is aiming to have a product list of advanced TEM sensors – including custom configurations – that will operate using a common set of acquisition parameters. The expectation is that there will be three standard settings for these parameters, depending on whether the instrument is used in cued/static mode or in survey/dynamic mode. In addition, an advanced mode option will be available for the customization of the acquisition parameter settings. The expectation is also that the output data will be standardized and exported in the form of an HDF5 file [4].

UX-Analyze [5] is an add-on to Geosoft's Oasis Montaj geophysical processing environment and its development has also occurred with support from ESTCP. In its current form, it can handle cued data from the MM and TEMTADS 2x2 systems, with dynamic data handling for these systems on the horizon. Using UX-Analyze, a data processor can apply physics-based models to measured sensor responses due to buried objects and estimate principal axis polarizability curves to compare with a library of known munitions curves. Geophysical contractors applying classification typically use the UX-Analyze software to extract the polarizability curves from collected sensor data to produce prioritized dig lists. To accommodate the next generation Geometrics systems, the expectation is that these systems' output HDF5 data files will be accepted for import and efficient processing into UX-Analyze.

The existing libraries in UX-Analyze have been successfully utilized in classification efforts to date. However, deficiencies do abound and this project addresses some of the more important shortcomings to these libraries. Specifically:

1. Until very recently, UX-Analyze dealt exclusively with cued data, and so classification capabilities using survey data were not an option. Since dynamic data handling is currently being developed and soon to be implemented, there will be great interest in exploiting classification based on dynamically collected data using the next generation Geometrics advanced TEM sensors. For this purpose, a munitions classification library applicable to the proposed standard dynamic mode acquisition parameters setting will be crucial.

2. The existing libraries consist of two separate libraries each dedicated to a specific sensor – the MM and the TEMTADS. This division is artificial and based solely on the legacy choice of acquisition parameter settings for each system. The TEMTADS was designed based on the desire to allow the body eddy currents to more fully develop and decay in larger munitions items. For this reason, longer on and off times were specified for the transmit coil current excitation. A more natural division for the libraries should be based on these on and off times instead. Figure 1.1 shows the resulting polarizations for a 57mm projectile with three different transmit on and off times (a duty cycle of 50% ensures that the on and off durations are the same). These represent the three standard proposed acquisition settings, with the 25 ms decay belonging to the current TEMTADS library, the 8.33 ms decay to the current MM library and the 2.78 ms decay being the expected dynamic mode setting. Throughout this report, the three standard acquisition settings will be referred to, respectively, by the shorthand 25, 8 and 3 ms decay settings.

3. The existing libraries include little to no metadata for the munitions item entries.

4. The libraries include all the common munitions items, but are missing many less common items.

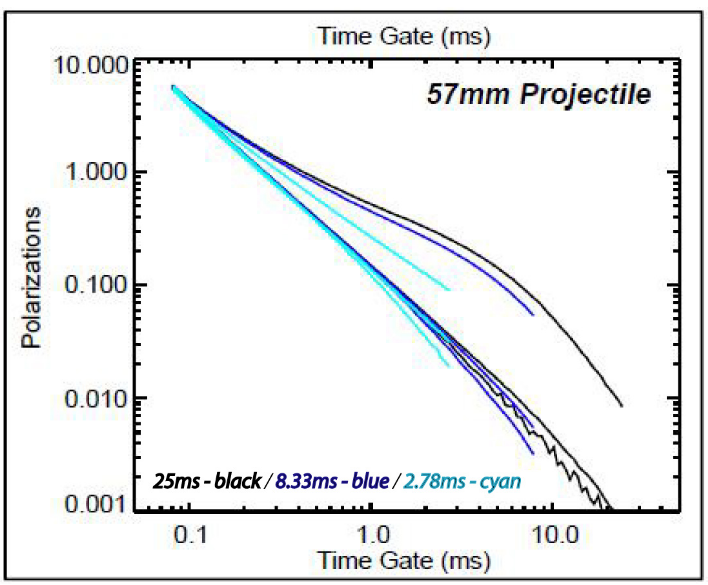

Figure 1-1 – Polarizations for a 57 mm projectile for different transmit coil current on/off times

1.2 OBJECTIVES OF THE DATA COLLECTION

Based on the observed shortcomings listed in the previous section, the objectives of the data collection were to:

1. Produce three classification libraries of polarizability curves for common munitions, each with a different decay length – i.e. 3, 8 and 25 ms – corresponding to the standard dynamic and static mode settings proposed by Geometrics for their advanced TEM systems. The libraries will then be applicable to all advanced TEM sensors – past and future – with the particular library being used depending on the acquisition parameters chosen during data collection.

2. Include a standardized complete set of metadata for all munitions item entries.

3. Acquire data over less common munitions to expand the existing libraries' munitions inventory.

4. Develop a standard operating procedure (SOP) that will allow members of the community to make their own additions to any, or all, of the classification libraries.

2.0 TECHNOLOGY

Three different sensor systems were used during the initial phase of the data collection: a modified PEDEMIS [6]; a TEMTADS 2x2; and a MM. All systems are based on hardware technologies developed by G&G Sciences over the years through NAVSEA, SERDP and ESTCP funding. The PEDEMIS was modified specifically for this project so that it effectively acted as a TEMTADS 3x3. The added spatial coverage that the 3x3 offered over the 2x2 (i.e. by the extra five transmitter/receiver sensor combinations) provided additional "look angles" to the target and helped in the determination that the estimated polarizability curves were indeed intrinsic to the munitions item. In this way, use of only the MM was justified for the second phase of the data collection.

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Advanced TEM Sensor Components

2.1.1.1 Transmitter Coils

There are currently two types of transmitter (TX) coils. The larger TX coils are 1 m square loops with 10 turns and are part of the MM design (see Figure 2-5). The smaller 35 cm square TX coils with 25 turns are shown in Figure 2-1 with an inset Styrofoam mold for snug placement of a tri-axial receiver (RX) cube at the center. Both the modified PEDEMIS (MPEDEMIS) and the TEMTADS 2x2 use this TX/RX coil combination as the basic building block for their systems.

Figure 2-1 – TX/RX coil combination that forms the basis for both the MPEDEMIS and the TEMTADS 2x2

2.1.1.2 Tri-axial Receiver Cubes

Each tri-axial RX cube has three orthogonal coils all of slightly different sizes and number of turns (see Figure 2-2 for a close up). The number of turns of each coil varies so that the difference in size is compensated for and there is no difference in the effective gain between the coils. The latest RX cubes are similar in design to those used in the second-generation Advanced Ordnance Locator (AOL) [7] and the first generation Geometrics MM system but with dimensions of 8 cm rather than 10 cm.

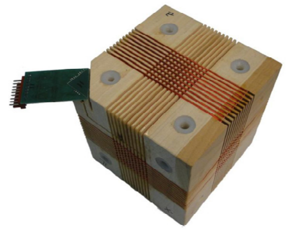

Figure 2-2 – A close up of the tri-axial RX cube

2.1.2 PEDEMIS

The original configuration of PEDEMIS, as shown in Figure 2-3, consisted of a coplanar 3x3 array of 34 cm square TX coils with a separate movable 56 cm square array of tri-axial RX cubes. The vertical non-metallic handle on the RX array is there to facilitate maneuverability. The TX array has a center-to-center distance of 40 cm yielding a 120 cm square array. The RX array schematic representation shows a 3x3 configuration with 20 cm center-to-center spacing. The modification simply dismantles the RX array and fixes each RX cube in the center of each TX coil, as discussed in Section 2.1.1.1. The default dataset for this system is composed of 9 transmitters x 9 receivers x 3 components, or 243 secondary magnetic field decays. The start and end times of the decays, as well as number of gates, will depend on the specifics of the acquisition parameter settings.

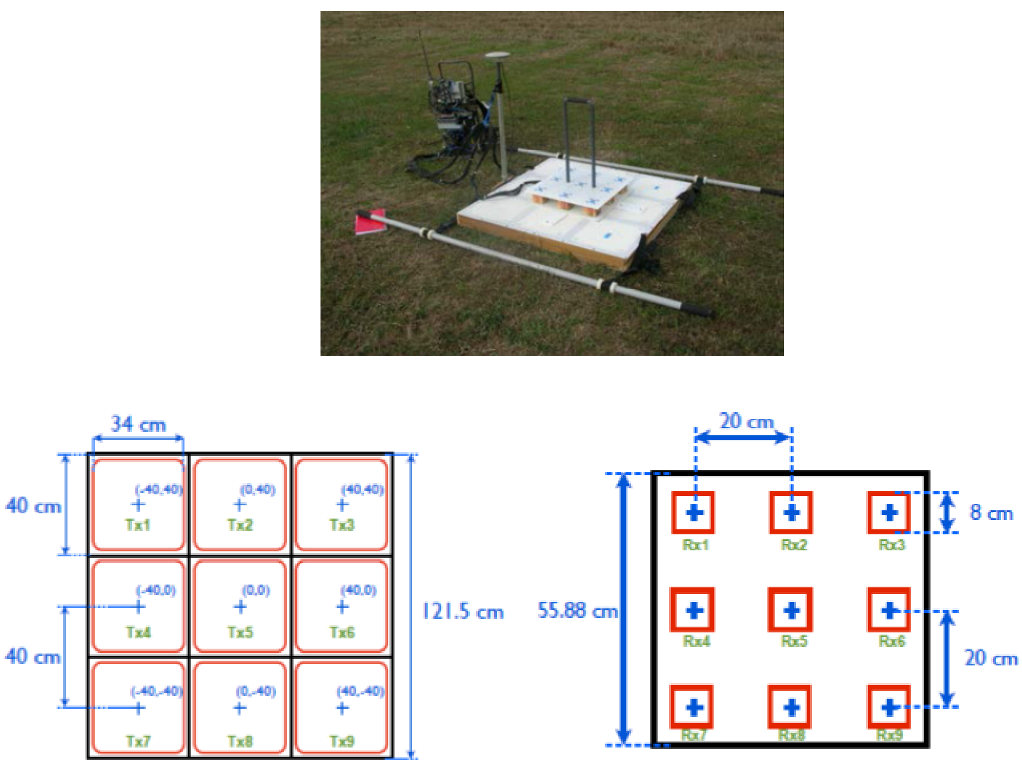

Figure 2-3 – The original PEDEMIS with schematics showing the TX array (left) and the RX array (right). The modification dismantles the RX array and fixes each RX cube in the center of each TX coil.

2.1.3 TEMTADS 2x2

The TEMTADS 2x2 is a man-portable system comprised of four TX/RX combination sensors as discussed in Section 2.1.1.1 and arranged in a 2x2 array as shown schematically in Figure 2-4. The center-to-center distance is 40 cm yielding an 80 cm square array. The system is fabricated from PVC plastic and fiberglass with the array typically deployed on a set of wheels resulting in a sensor-to-ground offset of approximately 18 cm. The transmitter electronics and the data acquisition computer are mounted in the operator backpack. The default dataset for this system is composed of 4 transmitters x 4 receivers x 3 components, or 48 secondary magnetic field decays. The acquisition parameter settings will determine the start and end times of the decays, as well as number of gates recorded.

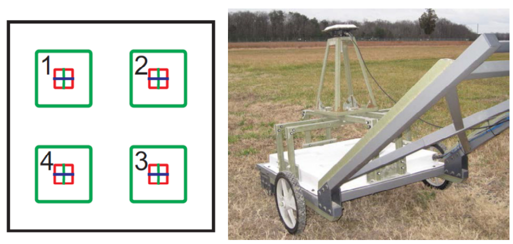

Figure 2-4 – The TEMTADS 2x2 with schematic

2.1.4 MetalMapper

The MM consists of three larger TX coils (as discussed in Section 2.1.1.1) oriented orthogonally to each other and aligned in a manner consistent with the tri-axial RX cubes. Referring to Figure 2-5, the Z (horizontal) TX coil is the bottom coil and contains the RX cubes within the box frame. The schematic shows the location of the RX cubes which are spaced every 13 cm perpendicular to the line of travel. The bottom coil is the only TX coil that is required during dynamic data acquisition. The X and Y TX coils are the vertical coils and are of slightly different

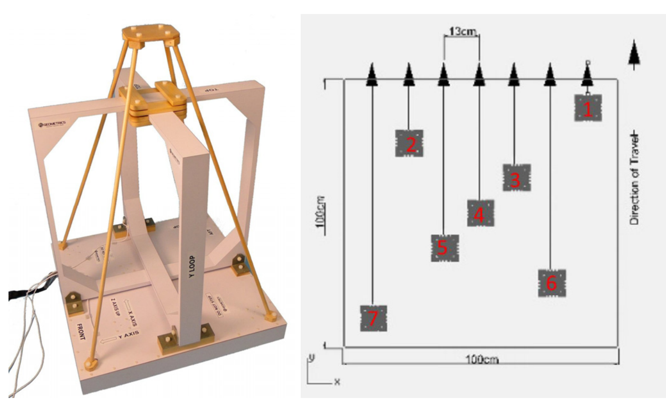

Figure 2-5 – The MM with a schematic showing the positions of the RX cubes within the bottom Z TX coil box frame

size in order to fit together. The default static dataset for this system is composed of 3 transmitters x 7 receivers x 3 components, or 63 secondary magnetic field decays. Again, the

acquisition parameter settings will determine the start and end times of the decays, as well as number of gates recorded.

3.0 PERFORMANCE OBJECTIVES

The performance objectives for the data collection were established and validated during the first phase and reported on in a technical report [8]. These provided the basis for evaluating whether or not the data collected were successful in meeting the project objectives and has been incorporated into the SOP (section 4 of Appendix C).

The first three performance objectives ensure that the requisite amount of data is collected for each munitions item on the library inventory list. The fourth applies to all data sets collected specifically for the purpose of extracting polarizability curves to add to the libraries and ensures that these estimated curves are sufficiently accurate. The fifth and sixth performance objectives apply to ensuring that the system responds to a standard object as expected (i.e. calibration) and that it remains stable throughout the collection period (i.e. repeatability).

4.0 DATA COLLECTION

Two phases of data collection were envisioned to achieve the objectives outlined in section 1.2. The first phase entailed data collection over common munitions items addressing: (1) the viability of using one advanced TEM sensor to produce the three classification libraries to be used by any advanced TEM sensor; and (2) the development of a SOP that will allow members of the community to make their own additions to any, or all, of the classification libraries. The next phase entailed data collection over less common munitions items.

4.1 PHASE 1: BLOSSOM POINT

Data collection at the Blossom Point Army Research Laboratory facility took place during August 28 – November 24, 2014. All items that were selected from the existing munitions collection were measured using the MPEDEMIS over a period of three weeks. The items are listed in Table 4-1 below with descriptor columns detailing the exact type and condition of each item, as well as whether they were also measured using the MM and TEMTADS 2X2. An additional week was spent measuring 43 of the items with the MM and an additional 2 days were spent measuring 20 of the items with the TEMTADS 2X2.

Table 4-1 – The 66 items (58 munitions + 8 standard objects) that belong to the Blossom Point common munitions collection and that were measured by the MPEDEMIS. Subsets of the items were also measured by the MM and 2X2 sensors as indicated by their respective columns – Y for 'yes' and 'N' for 'no'.

Name	Mark/Mod	Class[1]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[2]	MM	2X2	Comments
20mm TP-T	M220	P	N	N	N	Y	F/W	Y	Y	NRL 18
20mm TP-T	M220	P	N	N	N	Y	F/W	N	N	NRL 52
20mm TP	M55A3B1	P	N	N	N	Y	U/P	Y	Y	
20mm TP	M55A3B1	P	N	N	N	Y	U/P	Y	N	With Cartridge
25mm	M794	P	N	N	N	N	P	Y	N	With Cartridge
37mm	M74 AP-T	P	N	N	N	Y	U/P	Y	N	N00173-381
37mm	M74 AP-T	P	N	N	N	Y	F/W	Y	Y	NRL37-1
37mm	M74 AP-T	P	N	N	N	Y	F/W	Y	N	NRL37-3
37mm	M74 AP-T	P	N	N	N	Y	F/W	Y	N	NRL37-4
37mm	M74 AP-T	P	N	N	N	Y	F/W	Y	Y	NRL37-6
37mm	Mk2 HE	P	N	Y	N	Y	F/W	Y	N	
37mm	Mk2 HE	P	N	N	N	Y	F/W	Y	N	
37mm	Hotchkiss	P	N	N	N	Y	U/P	Y	N	French (pre WWI)
37mm	Mk1 LE	P	N	N	N	Y	F/W	Y	N	LE=Low Explosive
37mm	M59	P	N	N	N	N	F/W	Y	Y	
37mm	M80 TP-T	P	N	N	N	N	F/W	Y	N	
40mm	M385A1	G	N	N	N	Y	U/P	Y	N	
40mm	M918TP	G	N	N	N	Y	F/W	Y	Y	
40mm	Mk2	P	N	N	N	Y	F/W	Y	N	
40mm	Mk2 Mod12	P	N	Y	N	Y	U/P	Y	N	

Name	Mark/Mod	Class[1]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[2]	MM	2X2	Comments
40mm	Mk2 Mod26	P	N	Y	N	Y	U/P	Y	Y	
57mm AP-T	M70	P	N	N	N	Y	U/P	Y	Y	NRL57-002
57mm AP-T	M70	P	N	N	N	Y	F/W	Y	N	NRL57-005
60mm	M49A2	M	Y	Y	N	N	F/W	N	N	NRL60-1
60mm	M49A2	M	Y	Y	N	N	F/W	Y	N	NRL60-120
60mm	M49A2	M	Y	N	N	N	F/W	Y	Y	
60mm	M49A2	M	N	N	N	N	F/W	Y	N	
60mm	M49A5	M	Y	Y	N	N	U/P	Y	Y	
75mm	Mk I shrapnel	P	N	N	N	Y	F/W	N	N	
75mm	Mk I shrapnel	P	N	N	N	N	F/W	N	N	
76mm HEAT	M496	M	Y	Y	N	N	U/P	N	N	
81mm	M374	M	Y	Y	N	N	U/P	Y	N	
81mm	M374	M	N	N	N	N	U/P	N	N	
81mm	M43A1	M	Y	N	N	N	F/W	N	N	
81mm	M821	M	Y	N	N	N	U/P	Y	Y	
105mm	M84	P	N	N	N	N	F/W	N	N	Smoke
105mm	M84	P	N	N	N	Y	F/W	N	N	Smoke
105mm	M1	P	N	Y	N	Y	U/P	Y	Y	
105mm	M314A3	P	N	Y	N	Y	F/W	N	N	Illumination; no base
105mm HEAT	M456A1	P	Y	Y	N	N	U/P	Y	Y	
120mm	M931	M	Y	N	N	N	U/P	Y	N	
155mm	M107	P	N	Y	N	Y	U/P	Y	Y	
155mm	M741	P	N	Y	N	Y	U/W	N	N	Dispensing
Hand Grenade	M21	G	N	Y	N	N	P	Y	N	Practice
Rifle Grenade	M11A3	G	Y	Y	N	N	F/B	N	N	Practice, bent fins
Rifle Grenade	M31	G	Y	Y	N	N	F/B	N	N	Practice
Rockeye	MK118	S	Y	Y	N	N	U/P	N	N	Practice
25-lb	Mk76	B	Y	N	N	N	F/B	N	N	BDU-33 Practice Bomb
2.25-in SCAR	Mk4 Mod0	R	Y	Y	N	N	F/W	Y	N	With Motor
2.36-in	M6	R	Y	Y	N	N	F/W	N	Y	Bazooka
2.36-in	M7	R	Y	Y	N	N	F/W	N	N	Bazooka ; Partial fin; no nose cone
2.75-in	M151 HE	RWH	N	Y	N	N	U/P	N	N	
2.75-in	Mk1	RWH	N	Y	N	N	F/W	Y	N	
3-in	Stokes Mortar	P	N	Y	N	N	F/W	N	N	
4.2-in	M329A2 HE	P	Y	N	N	Y	F/P	Y	N	
4.2-in	M2A1	P	Y	N	N	Y	F/W	Y	N	
4.2-in	M335A2	P	N	Y	N	Y	F/W	N	N	
8-in	M106	P	N	Y	N	Y	U/P	Y	N	
Large ISO40		SO	N	N	N	N	Pristine	N	N	
Large ISO80		SO	N	N	N	N	Pristine	N	Y	

Name	Mark/Mod	Class[1]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[2]	MM	2X2	Comments
Medium ISO40		SO	N	N	N	N	Pristine	N	N	Rusty
Medium ISO80		SO	N	N	N	N	Pristine	Y	Y	
Small ISO40		SO	N	N	N	N	Pristine	Y	N	
Small ISO80		SO	N	N	N	N	Pristine	Y	Y	
4in Sphere		SO	N	N	N	N	Pristine	Y	Y	aluminum
4in Sphere		SO	N	N	N	N	Pristine	Y	Y	steel

[1] P = Projectile; G = Grenade; M = Mortar; R = Rocket; S = Submunition; B = Bomb; RWH = Rocket Warhead; SO = Standard Object

[2] F/W = Fired/Weathered; U/W = Unfired/Weathered; F/P = Fired/Pristine; U/P = Unfired/Pristine; F/B = Fired/Bent

The SOP was drafted early in the data collection with the MPEDEMIS and subsequently exercised and revised during data collection with the MM. The current working version is in Appendix C.

4.1.1 Equipment Setup

The equipment was setup in accordance with the procedures and guidelines outlined in section 3.1 of the SOP (Appendix C). Figure 1 of the SOP shows the setup established at Blossom Point for data collection with the MM.

The acquisition parameters used for the three sensors are shown in Tables 4-2 – 4-4. Because the TEMTADS has a different receiver channel digitizer with twice the temporal resolution that the other sensors have, our original plan of using the identical acquisition parameter settings for all three sensors could not be realized. The result is a slightly different set of decay times over the three decay lengths for the 2X2.

Table 4-2 – Fixed acquisition parameter settings used for the MPEDEMIS and MM

# of Stacks	# of Repeats	Gate Window Width (%)	Gate Hold-off Time (μs)	Once/Continuous	TX Coils
20	9	5	50	Once	All

Table 4-3 – TBlock acquisition parameter setting used for the MPEDEMIS and MM

Sensor System	Library Decay Length (ms)	TBlock (s)
MPEDEMIS	3	0.1
	8	0.3
	25	0.9
MM	3	0.1
	8	0.3
	25	0.9

Table 4-4 – Acquisition parameter settings used for the TEMTADS 2X2

Library Decay Length (ms)	# of Stacks	# of Repeats	Gate Window Width (%)	Gate Hold-off Time (μs)	TBlock (s)	Once/ Continuous	TX Coils
3	60	3	5	50	0.033	Once	All
8	180	1	5	50	0.033	Once	All
25	180	1	5	50	0.1	Once	All

4.1.2 Data Collection Procedures

The data collection procedures and guidelines are fully outlined in the SOP (Appendix C). This starts with an initial system check (section 3.2), followed by the system calibration check (section 3.3) and a few other steps (section 3.4) before getting into the data collection activities (sections 3.5-3.7). All inversions of library quality data collected over each munitions item as stipulated by the steps of section 3.6C of the SOP were held to MQO 4 of section 4 of the SOP.

4.2 PHASE 2: CAMP LEJEUNE, EGLIN AND 29 PALMS

The second phase entailed collecting data with just one advanced TEM system – the MM, in this case – over less common munitions items. The list of munitions to include was developed by surveying geophysicists from the NAOC technology committee, USACE geophysicists, and representatives of the Navy and Air Force. The compiled list was then sent to various curators of munitions collections and three places in particular were identified as good candidates to go visit: the EOD facility at MCB Camp Lejeune, the Navy EOD School/Range OPS at Eglin AFB and the EOD facility at MCB 29 Palms.

Data at Camp Lejeune were collected with the MM over 51 unique items. This occurred over a period of 5 days during June 22 – 26, 2015. The collection took place outdoors on the first day (Figure 4-1, left panel) and subsequently moved indoors (Figure 4-1, right panel) as wind was being forecasted. The items measured ranged in size from smaller submunitions all the way up to a 175mm projectile and a full 2.75-in rocket, and included many grenade and landmine varieties (Figure 4-2). The specifics of each of the items are tabulated in Table 4-5.

Figure 4-1 – Outdoor and indoor setups during the Camp Lejeune data collection.

Figure 4-2 - Munitions items measured at Camp Lejeune.

Data at Eglin were collected with the MM over 67 unique items. This occurred over a period of 10 days during July 28 – August 6, 2015. The collection took place indoors (Figure 4-3). The items measured focused on larger items, but again ranged in size from smaller munitions, including more grenade and landmine varieties, to much larger munitions such as the 16-inch projectile (Figure 4-4, left panel) and the Mk6 underwater mine (Figure 4-4, right panel). The specifics of each of the munitions items collected at Eglin are also tabulated in Table 4-5.

Figure 4-3 – The indoor setup at Eglin

Figure 4-4 – Measuring the 16-inch projectile (left) and Mk6 underwater mine (right).

Data at 29 Palms were collected with the MM over 38 unique items. This occurred over a period of 5 days during February 1 – February 5, 2016. The collection took place indoors (Figure 4-5). Focus was on collecting as many of the remaining outstanding desired items as possible and ranged in size from very small munitions (50 cal) all the way up to a 250-lb bomb and included a number of grenade varieties with two White Phosphorous (WP) examples (Figure 4-6). The specifics of each of the munitions items collected at 29 Palms are also included in Table 4-5.

Figure 4-5 – The indoor setup at 29 Palms

Figure 4-6 – Two WP hand grenades – the M15 (left) and the M34 (right) – measured at 29 Palms

Table 4-5 – The additional 156 munitions items that were measured only with the MM during Phase 2 of the data collection. The first 51 items belong to the MCB Camp Lejeune EOD facility munitions collection; the next 67 items belong to the Navy EOD School/Range OPS munitions collection at Eglin AFB; and the last 38 items belong to the MCB 29 Palms EOD facility munitions collection.

	Site[1]	Name	Mark/Mod	Class[2]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[3]	Comments
1	CL	120mm	xm1107	M	Y	N	N	N	U/P	Practice
2	CL	175mm	M439A2 HE	P	N	N	N	Y	U/P	
3	CL	2.75-in	M151 HE	R	Y	Y	N	N	U/P	
4	CL	2.95-in	18-lb cast iron solid shot	P	N	N	N	Y	F/W	
5	CL	25mm TP-T	M793	P	N	Y	N	Y	U/P	
6	CL	30mm TP-T	PGU-16/A	P	N	Y	N	Y	U/P	With Cartridge
7	CL	37mm	ERST	P	N	Y	N	Y	U/P	German

	Site[1]	Name	Mark/Mod	Class[2]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[3]	Comments
8	CL	37mm	Mk2 HE	P	N	N	N	Y	F/W	
9	CL	37mm	Mk1 LE	P	N	N	N	Y	F/W	
10	CL	37mm	M51	P	N	N	N	Y	F/W	
11	CL	40mm	M430 HEDP	G	N	N	N	Y	U/P	With 549 Fuse; with Cartridge
12	CL	40mm	M430 HEDP	G	N	N	N	Y	U/P	With 549 Fuse
13	CL	40mm	xm922 HV	G	N	N	N	Y	U/P	Dummy Round; with Cartridge
14	CL	60mm	M720 HE	M	Y	Y	N	N	U/P	
15	CL	60mm	M720 HE	M	Y	N	N	N	U/P	
16	CL	60mm	M720 HE	M	N	Y	N	N	U/P	
17	CL	60mm	M721	M	Y	Y	N	N	U/P	Illumination
18	CL	60mm	TAM 1.8	M	Y	Y	N	N	U/P	British
19	CL	60mm	M5 TP-SR	M	Y	Y	N	N	U/P	
20	CL	60mm	M5 TP-SR	M	Y	N	N	N	U/P	
21	CL	60mm	M5 TP-SR	M	N	Y	N	N	U/P	
22	CL	60mm	M302A2 WP	M	Y	Y	N	N	U/P	
23	CL	81mm	M853A1	M	Y	Y	N	N	U/P	Illumination
24	CL	81mm	M43A1 TP	M	Y	N	N	N	U/P	
25	CL	81mm	HE Type 100	P	Y	Y	N	N	U/P	Japanese
26	CL	90mm	M71A1	P	N	Y	N	Y	U/P	
27	CL	Bomblet	BLU 6/B	S	N	N	N	N	U/P	
28	CL	Bomblet	M42	S	N	N	N	N	U/P	
29	CL	Bomblet	M75	S	N	N	N	N	U/P	
30	CL	Booster Cup			N	N	N	N	P	
31	CL	Fuze	M110	B	N	Y	N	N	W	
32	CL	Hand Grenade	M67	G	N	Y	N	N	U/P	Fragmentation
33	CL	Hand Grenade	M67	G	N	Y	N	N	U/P	Fragmentation; with spoon
34	CL	Hand Grenade	HEAT Type 3	G	N	Y	N	N	U/P	Chinese
35	CL	Hand Grenade	MkI Mod2	G	N	Y	N	N	U	Illumination; with spoon
36	CL	Hand Grenade	MkI Mod2	G	N	Y	N	N	U	Illumination
37	CL	Hand Grenade	M14	G	N	Y	N	N	U	Incendiary
38	CL	Hand Grenade	M30	G	N	Y	N	N	U	Practice; with spoon
39	CL	Hand Grenade	M30	G	N	Y	N	N	U	Practice
40	CL	Hand Grenade	M18	G	Y	Y	N	N	U/P	Smoke; with spoon
41	CL	Hand Grenade	Stick Model 1917	G	N	N	N	N	U/P	
42	CL	Landmine	VS2.2 AP	LM	N	N	N	N	P	
43	CL	Landmine	VS-50 AP	LM	N	N	N	N	P	
44	CL	Landmine	M15 AT	LM	N	N	N	N	P	

	Site[1]	Name	Mark/Mod	Class[2]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[3]	Comments
45	CL	Landmine	TM46 AT	LM	N	N	N	N	P	
46	CL	Landmine	VS1.6 AT	LM	N	N	N	N	P	
47	CL	Rifle Grenade	M31 HEAT	G	Y	Y	N	N	U/P	
48	CL	Rifle Grenade	M22A2	G	Y	Y	N	N	U/P	
49	CL	Rifle Grenade	A/P PGR	G	Y	Y	N	N	U/P	Rocket assist
50	CL	Rifle Grenade	M18	G	Y	Y	N	N	U/P	Smoke; with projection adapter
51	CL	Rifle Grenade	M19 WP	G	Y	Y	N	N	U/P	Smoke
52	EAFB	100-lb	AN-M30A1	B	Y	N	N	N	U/P	GP Bomb
53	EAFB	100-lb	AN-M30A1	B	N	N	N	N	U/P	GP Bomb
54	EAFB	105mm	xm314A2E1	P	N	Y	N	Y	U	Illumination Round
55	EAFB	105mm	xm314A2E1	P	N	N	N	Y	U	Illumination Round
56	EAFB	105mm SABOT		P	Y	N	N	N	P	
57	EAFB	105mm SABOT		P	Y	N	N	N	P	
58	EAFB	105mm SABOT		P	N	N	N	N	P	
59	EAFB	106mm	M344 Recoiless	P	Y	Y	N	Y	U/P	
60	EAFB	10-lb B	BDU-48/B	B	Y	Y	N	N	U/P	Practice
61	EAFB	152mm	Concrete Piercing	P	N	N	N	Y	U/P	USSR/Foreign
62	EAFB	152mm	HE	P	N	Y	N	Y	U/P	USSR/Europe; with RGM-2 Fuze
63	EAFB	155mm	M110A2	P	N	N	N	Y	U	WP Smoke
64	EAFB	16-in	Mk13 Mod2	P	N	N	N	Y	W	
65	EAFB	2.36-in Rocket Motor		R	Y	Y	N	N	U/P	
66	EAFB	2.36-in	M6	R	Y	Y	N	N	U/P	Bazooka; with Motor; with Fins
67	EAFB	2.36-in	M6	R	N	Y	N	N	U/P	Bazooka; with Motor; without Fins
68	EAFB	2.36-in	M6	RWH	N	N	N	N	U/P	Bazooka warhead
69	EAFB	2.75-in Rocket Motor	Mk40 Mod3	R	Y	N	N	N	U/P	
70	EAFB	20-lb	AN-M42	B	Y	N	N	N	W	Fragmentation
71	EAFB	20mm	HE-T Type 100	P	N	Y	N	Y	P	Japanese; self destruct
72	EAFB	250-lb	Mk81	B	N	N	N	N	W	GP Bomb
73	EAFB	25-lb	Mk76	B	Y	N	N	N	R/W	BDU-33 Practice Bomb
74	EAFB	3.5-in Rocket Motor		R	Y	N	N	N	W	
75	EAFB	3.5-in	M30A1	R	Y	Y	N	N	W	WP Smoke; with M405 Dummy Fuze and Motor
76	EAFB	3.5-in	M30A1	R	N	Y	N	N	W	WP Smoke; with M405 Dummy Fuze but without Motor

	Site[1]	Name	Mark/Mod	Class[2]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[3]	Comments
77	EAFB	30mm TP	PGU-15/B	P	N	Y	N	Y	P	Without Cartridge
78	EAFB	3-in	Stokes Mortar	P	N	Y	N	N	U/R	
79	EAFB	4.52-in	Parrot	P	N	N	N	N	F/W	
80	EAFB	4.5-in Rocket Motor		R	N	N	N	N	W	Barrage
81	EAFB	4.5-in	T160E5 HE	R	N	N	N	N	W	Spin Stabilized; Barrage; with Motor
82	EAFB	4.5-in	T160E5 HE	RWH	N	N	N	N	W	Spin Stabilized; Barrage
83	EAFB	40mm	Mk285 Mod0 PPHE	G	N	N	N	Y	U/P	With Cartridge
84	EAFB	4-in	Stokes Mortar	P	N	N	N	N	R/W	
85	EAFB	50 cal		C	N	N	N	N	U/P	Cartridge case only
86	EAFB	5-in	Mk48 Mod1	P	N	N	N	Y	P	Illumination Round
87	EAFB	5-in	Mk33	RWH	N	Y	N	N	P	Eject Flare
88	EAFB	5-in	Mk33	RWH	N	N	N	N	P	Eject Flare
89	EAFB	5-in	Mk32 Mod0	RWH	N	Y	N	N	P	
90	EAFB	5-in	Mk32 Mod0	RWH	N	N	N	N	P	HEAT
91	EAFB	5-lb	Mk106	B	Y	N	N	N	R/W	Practice
92	EAFB	66mm	M74	R	N	Y	N	N	W	Incendiary; with motor
93	EAFB	66mm	M72A1	R	Y	Y	N	N	U	LAW; with coupler and motor
94	EAFB	6-in	READ Short Shell	P	N	N	N	N	F/W	
95	EAFB	7.2-in Depth Charge	Mousetrap	R	Y	Y	N	N	W	ASW; with depth charge Mk136 Fuze
96	EAFB	Fuze	Mk188 Mod0	RWH	N	Y	N	N	P	5-in Warhead
97	EAFB	Fuze	Mk193 Mod0	RWH	N	Y	N	N	P	Mech Time
98	EAFB	Fuze	AN-M110A1 PD	B	N	Y	N	N	P	
99	EAFB	Fuze	M48 PD	B	N	Y	N	N	P	PD=Point Detonation
100	EAFB	Fuze	M84 VT/PTTF	M	N	Y	N	N	P	VT/PTTF=Variable Time / Powder Train Time Fuze
101	EAFB	Fuze	xm565	P	N	Y	N	N	P	
102	EAFB	Fuze	Model 1907M PTTF	P	N	Y	N	N	P	
103	EAFB	Hand Grenade	M69	G	N	Y	N	N	U/P	Practice
104	EAFB	Landmine	M16A1 AP	LM	N	Y	N	N	P	Practice
105	EAFB	Landmine	M12 AT	LM	N	Y	N	N	W/D	Practice
106	EAFB	Landmine	M19 AT	LM	N	Y	N	N	W	Practice
107	EAFB	Landmine	M19 AT	LM	N	Y	N	N	P	Without Safety Clip
108	EAFB	Landmine	M19 AT	LM	N	Y	N	N	P	With Safety Clip
109	EAFB	Landmine	M21 AT	LM	N	Y	N	N	P	
110	EAFB	Landmine	M2A1/M48	LM	N	Y	N	N	P	With full base

	Site[1]	Name	Mark/Mod	Class[2]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[3]	Comments
			Trip Flare AP							
111	EAFB	Landmine	M2A1 AP	LM	N	Y	N	N	W	With partial base
112	EAFB	Depth Charge	Mk95 Mod0 SUS	DC	Y	Y	N	N	U/P	Dummy Round ; SUS = Signal Underwater Sound
113	EAFB	Parachute Flare	LUU-2B	F	N	Y	N	N	P	
114	EAFB	Rifle Grenade	M11A4 AT	G	Y	Y	N	N	U/P	Practice
115	EAFB	Rifle Grenade	M29	G	Y	Y	N	N	U/P	Missing a fin blade
116	EAFB	Rifle Grenade	M9A1	G	Y	Y	N	N	U/P	
117	EAFB	30-lb Smoke Pot	ABC - M5 HC	SP	N	N	N	N	W/D	
118	EAFB	Underwater Mine	Mk6	UM	N	N	N	N	W	
119	29P	105mm TP	M393A1	P	N	Y	N	Y	U/P	TP = Training Practice
120	29P	120mm TP/T	N831	P	Y	Y	N	N	U/P	With obturating band
121	29P	20mm	Mk12 HE-I	P	N	Y	N	N	U/P	Fuze Mk78; HE-I = High Explosive - Incendiary
122	29P	250-lb	AN-M57	B	Y	N	N	N	W	GP Bomb; AN = Army/Navy
123	29P	30mm TP	M788	P	N	Y	N	Y	U/P	For Apache gun system
124	29P	30mm TP	Mk2Z	P	N	Y	N	Y	U/P	British; for Aden gun system (Harrier?)
125	29P	30mm TP	Mk4Z	P	N	Y	N	Y	U/P	British
126	29P	35mm	M73	R	N	Y	N	N	U/W	Subcaliber; Practice; with plastic fins and no nose
127	29P	4.2-in	M329A1	P	N	Y	N	N	U/P	HE
128	29P	40mm TP	M918	P	N	Y	N	Y	U/P	
129	29P	50 cal	M962 APDS-T	P	N	N	N	N	U/P	SLAP-T with Cartridge; APDS-T = Armor Piercing Discarding Sabot - Tracer; SLAP-T = Saboted Light Armor Penetrator-T
130	29P	50 cal	M33	P	N	N	N	N	U/P	With Cartridge
131	29P	50 cal	M33	P	N	N	N	N	U/P	Without Cartridge
132	29P	5-in		RWH	N	N	N	N	W	With Protective Cap over threads
133	29P	60mm	M83A1	M	Y	Y	N	N	U/W	Illumination
134	29P	60mm	M83A1	M	N	Y	N	N	U/W	Illumination Candle Housing
135	29P	75mm	M309A1 HE Recoiless	P	N	Y	N	Y	U/P	With Fuze M557
136	29P	75mm	Mk1 Shrapnel	P	N	Y	N	Y	U/P	With Fuze M1907M
137	29P	75mm	M64	P	N	N	N	N	F/W	WP
138	29P	81mm	M301A3	M	Y	Y	N	N	U/P	Illumination
139	29P	90mm	M77	P	N	N	N	Y	U/P	AP/T = Armor

	Site[1]	Name	Mark/Mod	Class[2]	Fins	Fuse	Spotting Charge	Rotating Band	Condition[3]	Comments
		AP/T								Piercing/Tracer
140	29P	90mm TP/T	M353	P	N	Y	N	Y	U/P	Ballistic windshield intact
141	29P	Rockeye	Mk118 AT	S	Y	Y	N	N	U/P	
142	29P	Bomblet	M42	S	N	N	N	N	U/P	
143	29P	Fuze	M603 AT	LM	N	Y	N	N	U/P	Without Safety Clip
144	29P	Fuze	M603 AT	LM	N	Y	N	N	U/P	With Safety Clip
145	29P	Hand Grenade	M30/M62	G	N	Y	N	N	U	M30 vs M62: M62 has jungle safety clip; M30 does not. Otherwise the two are identical. Practice
146	29P	Hand Grenade	M30/M62	G	N	N	N	N	U	Practice
147	29P	Hand Grenade	M30/M62	G	N	Y	N	N	U	Practice; with spoon
148	29P	Hand Grenade	M7A3	G	N	Y	N	N	U	Riot CS
149	29P	Hand Grenade	M15	G	N	Y	N	N	U	WP
150	29P	Hand Grenade	M34	G	N	Y	N	N	U	WP Smoke; with spoon and safety pin
151	29P	Hand Grenade	M34	G	N	Y	N	N	U	WP Smoke
152	29P	Igniter Bomb	M23	B	N	Y	N	N	U/P	With Fuze FMU 7/B
153	29P	Igniter Bomb	M23	B	N	Y	N	N	U/P	With Fuze M918
154	29P	Landmine	M7 AT	LM	N	Y	N	N	U/P	M603 Fuze
155	29P	Rifle Grenade	M29	G	Y	Y	N	N	U/P	
156	29P	Dual Mode SMAW	Mk3 HE	R	N	Y	N	N	U/P	SMAW = Shoulder Multi-Purpose Assault Weapon

[1] CL – Camp Lejeune; EAFB = Eglin; 29P = 29 Palms
[2] P = Projectile; G = Grenade; R = Rocket; M = Mortar; S = Submunition; B = Bomb; RWH = Rocket Warhead; DC = Depth Charge; C = Cartridge; F = Flare, LM = Landmine, UM = Underwater Mine; SP = Smoke Pot
[3] F/W = Fired/Weathered; U/W = Unfired/Weathered; U/P = Unfired/Pristine; P = Pristine; U = Unfired; U/R = Unfired/Rusty; W = Weathered; W/D = Weathered/Dented

The equipment setup and the data collection procedures at all three places again followed the procedures and guidelines outlined in the SOP (Appendix C). The acquisition parameters used for the MM sensor were identical to the ones used during Phase 1 shown in Tables 4-2 – 4-3.

5.0 RESULTS

The calibration and repeatability measurements for all the advanced TEM sensors used during Phase 1 and 2 of the data collection followed section 3.3 of the SOP (Appendix C) and used a medium schedule 80 ISO (ISO80) as the standard object of choice. The reasons for this choice are enumerated in the SOP.

Based on Phase 1 results [8], it was determined that the different advanced TEM sensors respond to an object in the same way, thus justifying using only the MM for the Phase 2 data collection. Plots of the extracted polarizabilities from the daily medium ISO80 data collected by each of the three sensors at Blossom Point are reproduced below in Figure 5-1 to remind us of this fact. Furthermore, Figure 5-2 confirms the repeatability of MM measurements throughout the data collection. It should be mentioned that although the same medium ISO80 item was used at the first three sites, a different medium ISO80 item purchased directly from the online site provided by a link in the SOP was shipped for use at 29 Palms.

As far as measurements made on each item, although every effort was made to follow the SOP by acquiring the requisite six orientation/range scenarios, there were instances where this was not always possible nor practical. In these few cases, only the most efficient set of measurements scenarios were conducted with safety being the main concern.

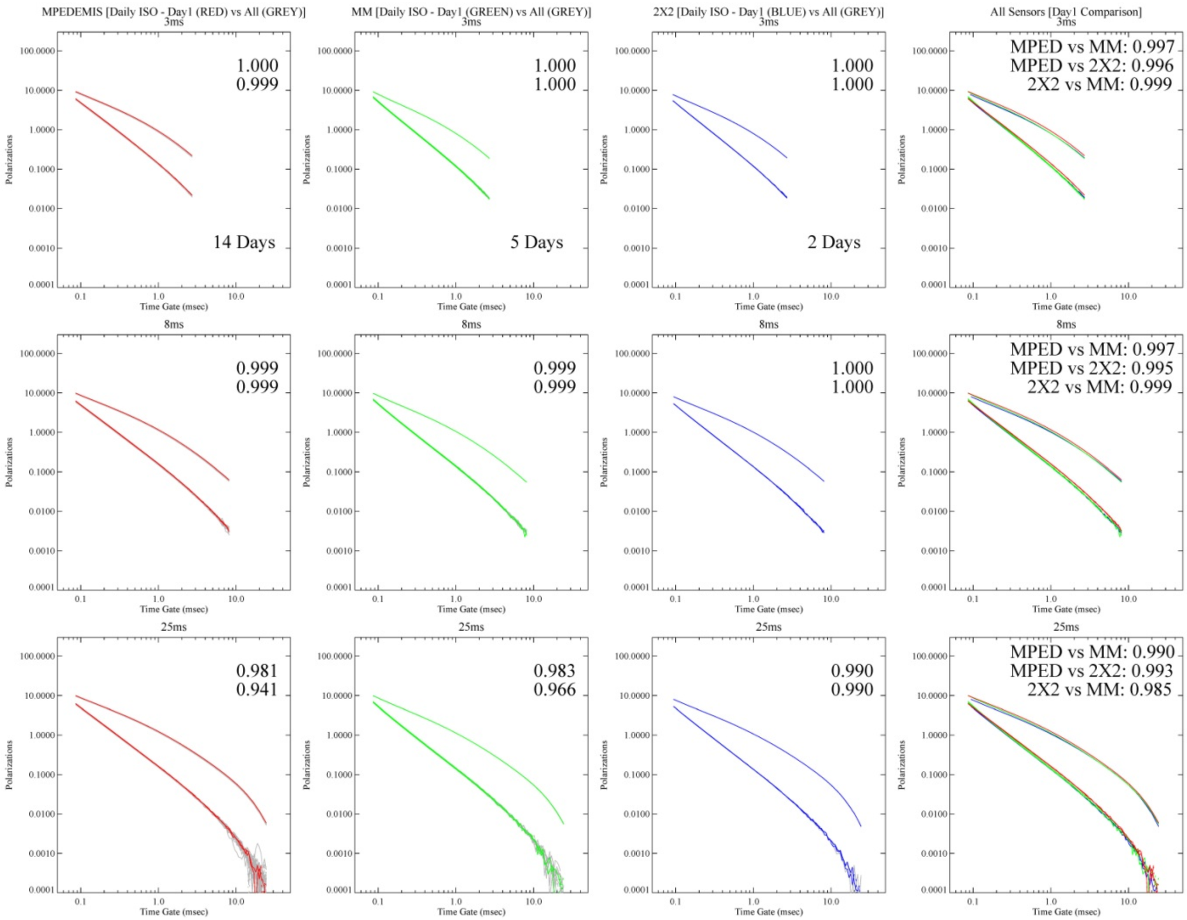

Figure 5-1 – The polarizabilities extracted from data collected by the three sensors – MPEDEMIS (red), MM (green) & 2X2 (blue) - for a medium ISO80 centered under the arrays. The rows show the 3ms, 8ms & 25ms decays, respectively, and the last column compares each decay length across sensors. The two numbers in the panels within the first three columns represent the average and worst values for the 3-curve match metric when comparing polarizabilities extracted from the first ISO data to all the remaining ISO data (14 days worth of data for the MPEDEMIS, 5 days for the MM & 2 days for the 2X2). The numbers in the panels within the last column represent the 3-curve match metric comparing the first ISO data for the stated sensors.

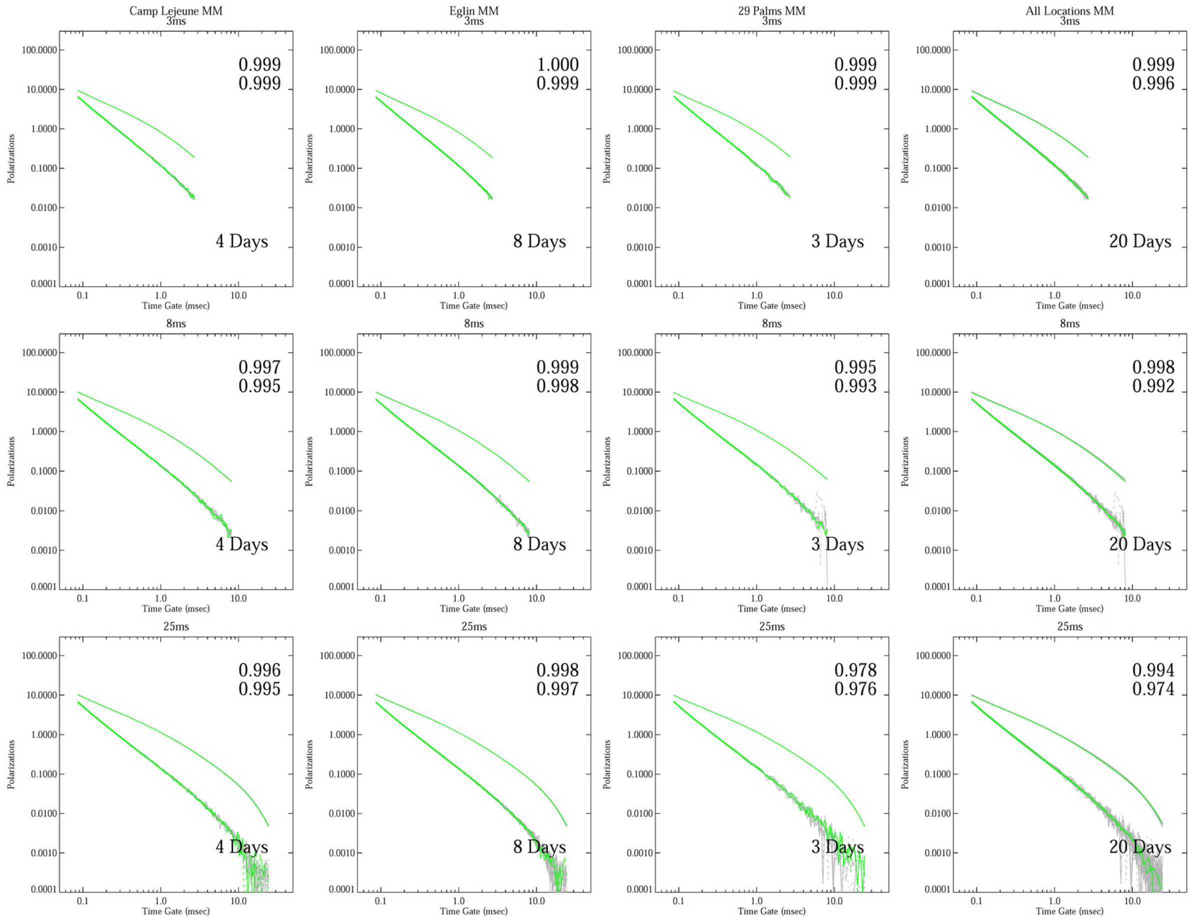

Figure 5-2 – The polarizabilities extracted from data collected by the MM at Camp Lejeune, Eglin, 29 Palms and all four locations (including Blossom Point) for a medium ISO80 centered under the arrays. The rows show the 3ms, 8ms & 25ms decays, respectively. The two numbers in the panels represent the average and worst values for the 3-curve match metric when comparing polarizabilities extracted from the first ISO data to all the remaining ISO data (4 days at Camp Lejeune, 8 days at Eglin, 3 days at 29 Palms & 20 days for all locations including Blossom Point).

5.1 FINAL DATA PRODUCTS

Two separate HDF5 file [4] formats were ultimately settled upon as the final data products for the project. HDF5 files are flexible enough to include a variety of data structures – including photos – making these ideal for keeping related things in one place. The two formats are the library munitions item HDF5 file and the library self-contained raw data HDF5 file. These are discussed in detail below.

5.1.1 Library Munitions Item HDF5 File

This format applies to every measured munitions item for each of the three classification libraries – i.e. 3, 8 and 25 ms decay lengths. Thus, for Camp Lejeune – where 51 items were measured – a total of 153 of these HDF5 files were generated, 51 for each of the three decay lengths. Each generated HDF5 file contains:

1. The item metadata. This represents all the useful descriptive information that can be obtained for a munitions item and includes all the information given by the row entries of Table 1 in Appendix A of the SOP (Appendix C) with enough photo views to fully convey the munitions item.

2. The item library data. This includes, for every item range/orientation scenario measured:
    - The measurement ground truth – i.e. the item orientation and distance; the sensor used and the decay length setting; and the raw data filenames for both data and background used in the parameter estimation
    - The estimated polarizability curves and the associated times (in seconds)
    - The additional estimated fit parameters – i.e. X, Y, Z, yaw, pitch, roll, model fit error and fit coherence

An example of what this HDF5 file format looks like when opened in HDFView, a free downloadable viewer, is shown in Figures 5-3 – 5-5. The munitions item is the first listed in Table 4-5, the 120mm Practice Mortar xm1107 for the 25ms library.

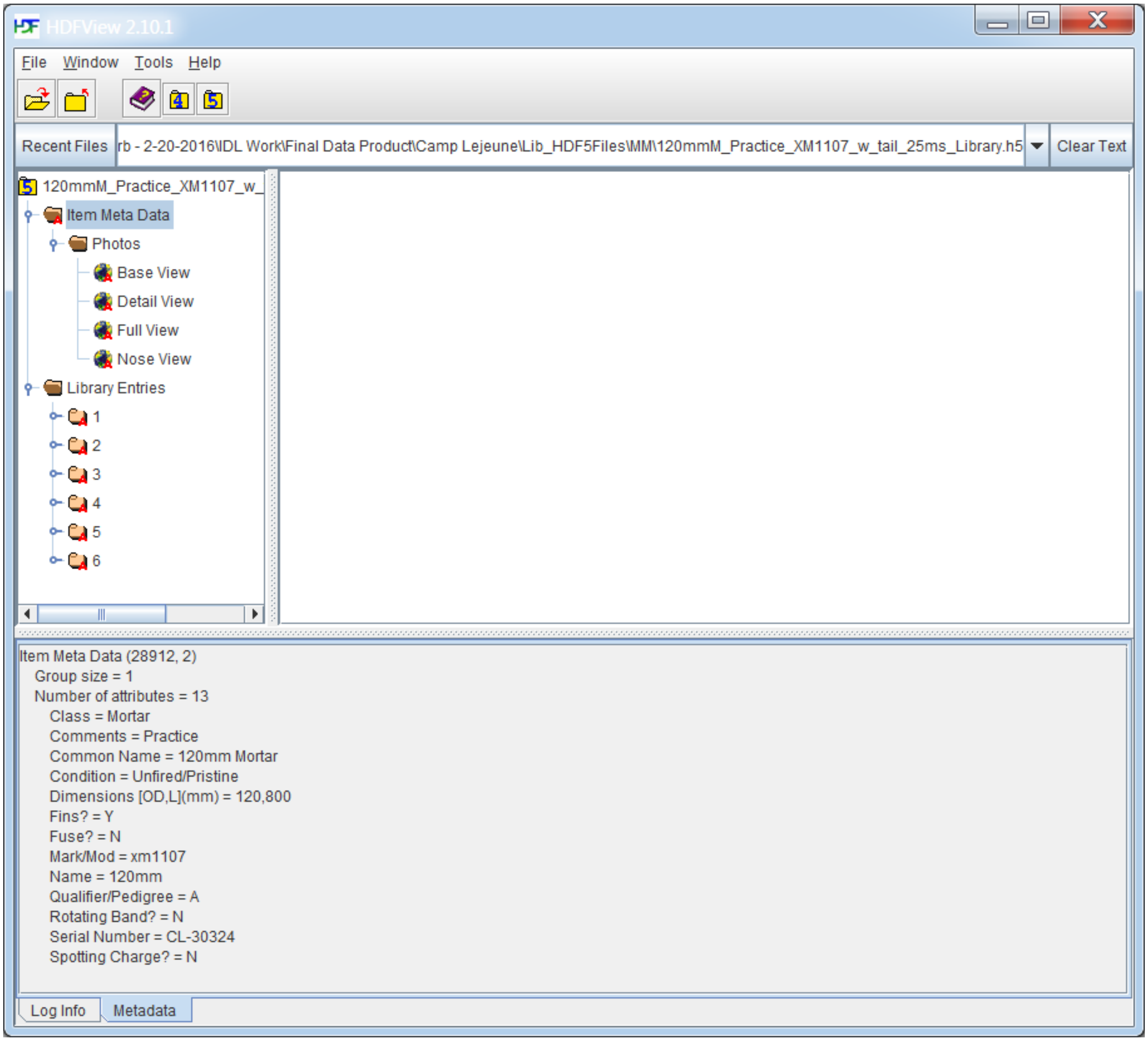

Figure 5-3 – The associated attributes for the highlighted **Item Meta Data** group are shown in the Metadata window. These represent all the useful descriptive information about the munitions item. Within the **Item Meta Data** group is the **Photos** sub-group which contains enough photo views to fully convey the munitions item. The **Library Entries** group contains the library data for every range/orientation scenario that was measured for the item.

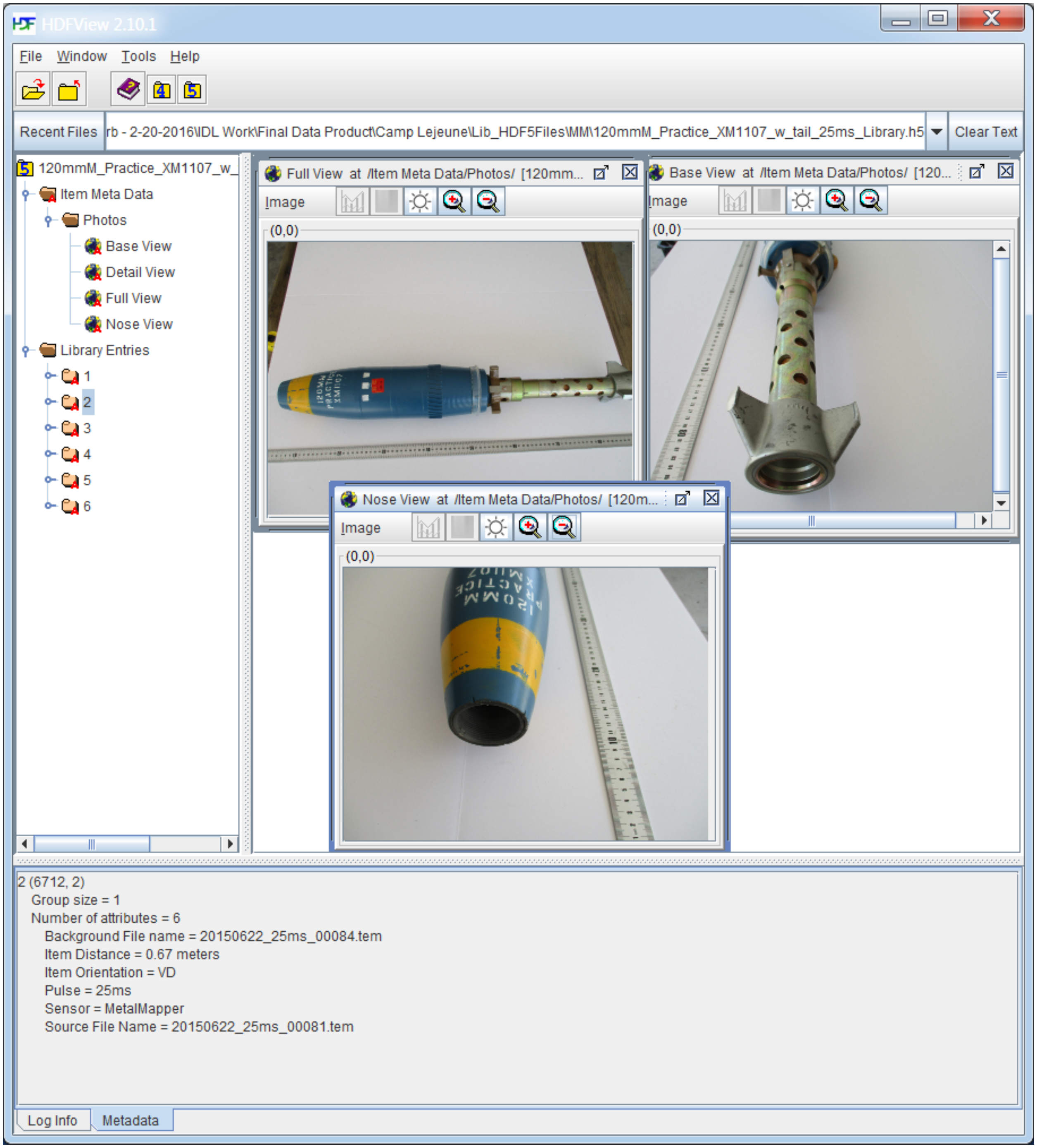

Figure 5-4 – Three of the four images within the **Photos** group are shown in the main window along with attributes for the highlighted **2** sub-group within the **Library Entries** group shown in the Metadata window. The attributes represent the measurement ground truth which, in this case, says that the item was oriented vertically nose down (VD) at a distance of 0.67 meters below the sensor and measured using the MM with the 25ms decay length setting.

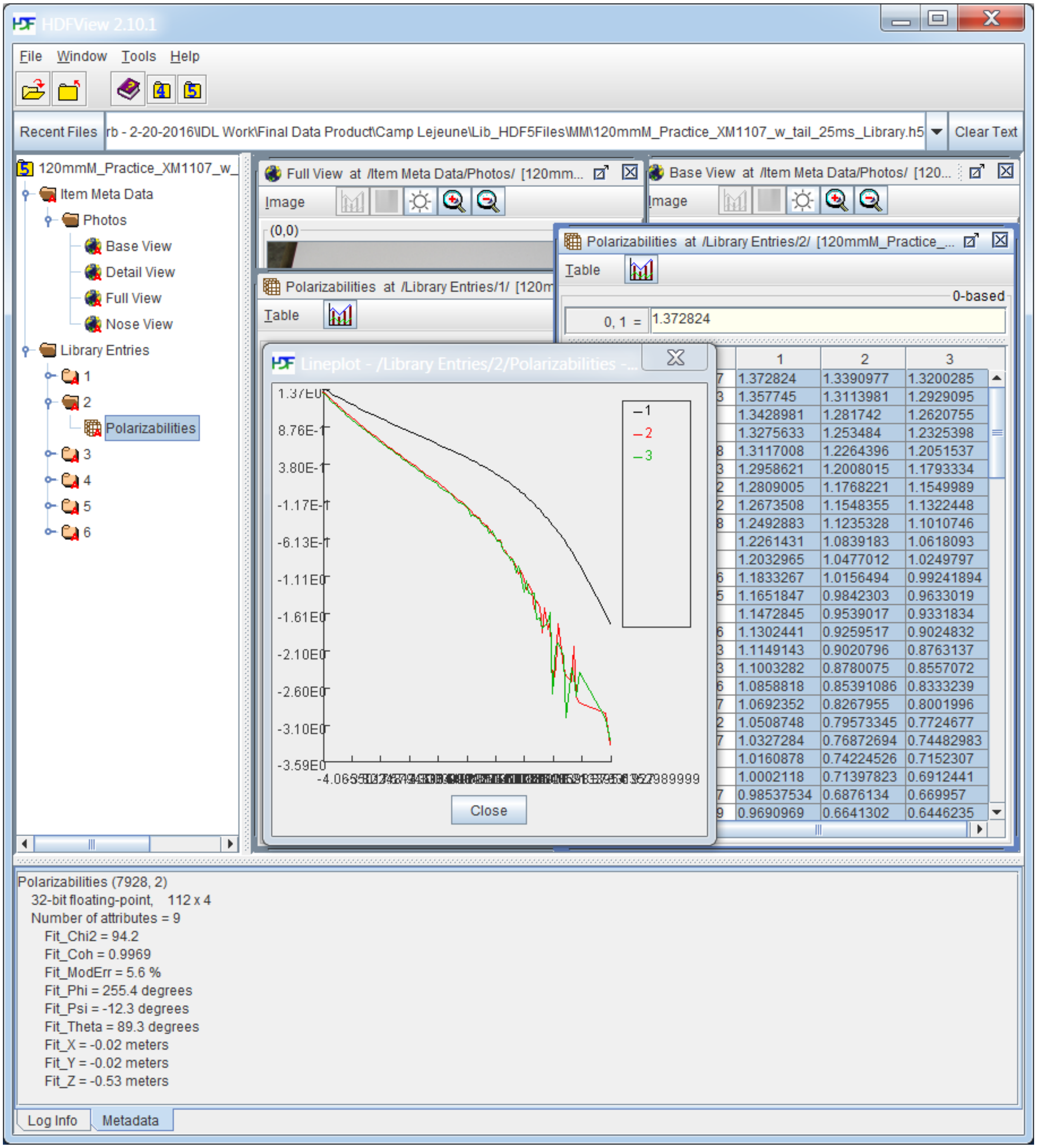

Figure 5-5 – The main window shows the data and a log-log plot for the polarizability curves estimated from the item range/orientation scenario dataset indicated by the **2** group attributes. The associated attributes for the highlighted **Polarizabilities** dataset are shown in the Metadata window. These represent the additional estimated fit parameters.

5.1.2 Library Self-Contained Raw Data HDF5 File

This format embeds the item metadata and library data, as well as the raw background data and data mask used, into the original raw data HDF5 file. The data mask are arrays equal in size to the transient datasets and populated with 1s for data used in the inversion and 0s for those not used. Since raw data HDF5 files will only start appearing with the very soon to be released next-generation Geometrics sensors, the HDF5 files assumed for this data product have been simulated based on the format Geometrics has settled upon.

An example of what this HDF5 file format looks like for the MM when opened in HDFView is shown in Figures 5-6 and 5-7. The raw data file is that referred to in Figure 5-4 above – i.e. for the 120mm Practice Mortar xm1107 oriented vertically nose down at a distance of 0.67 meters below the sensor and measured using the MM with the 25ms decay length setting. The data format replicates the expected next generation Geometrics sensors data format with the associated file attributes shown in the Metadata window (Figure 5-6) and the transients datasets organized in sub-groups based on the firing transmitters (Figure 5-7). The library data – in the form of the item metadata and item library data contents specified in section 5.1.1, the background raw data file, and the data mask – are embedded in a group within the raw data file after pre-processing and inverting the background-subtracted raw data have been completed. Figure 5-8 shows an additional example of what an HDF5 file format looks like for the 2X2 – in this case for data collected at Blossom Point over a 37mm french Hotchkiss projectile oriented horizontally at the closest range below the sensor and measured using the 2X2 with the 25ms decay length setting.

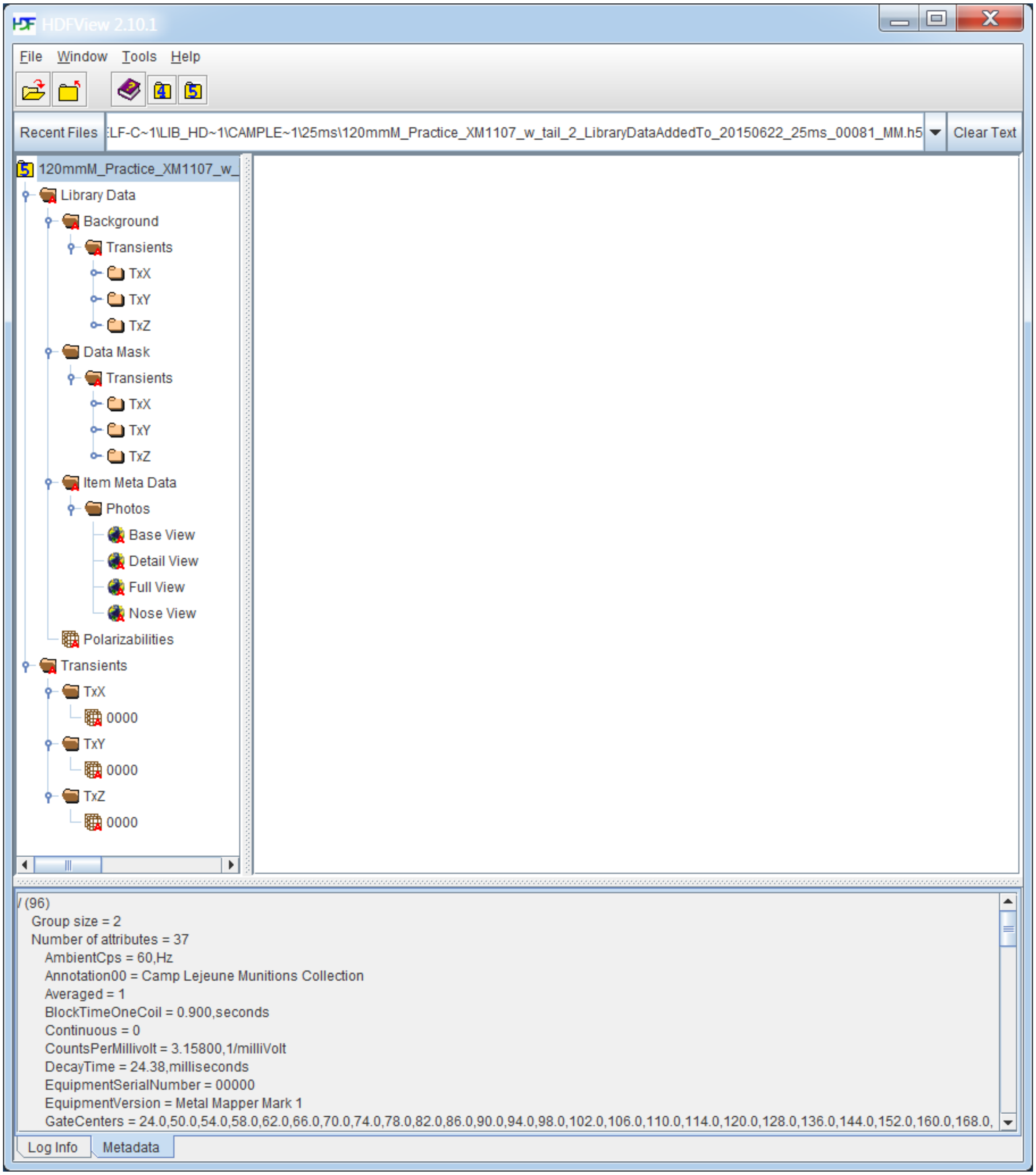

Figure 5-6 – An example of the library self-contained raw data HDF5 file for MM data. The data format replicates the expected next generation Geometrics sensors data format. The associated file attributes are shown in the Metadata window and include details on the acquisition parameter settings and sensor configuration. The file contains two groups – **Transients** (original to the file) and **Library Data** (added after collection and processing) – with the **Library Data** group containing the **Background** and **Data Mask** sub-groups, in addition to the **Item Meta Data** group and **Polarizabilities** dataset discussed previously.

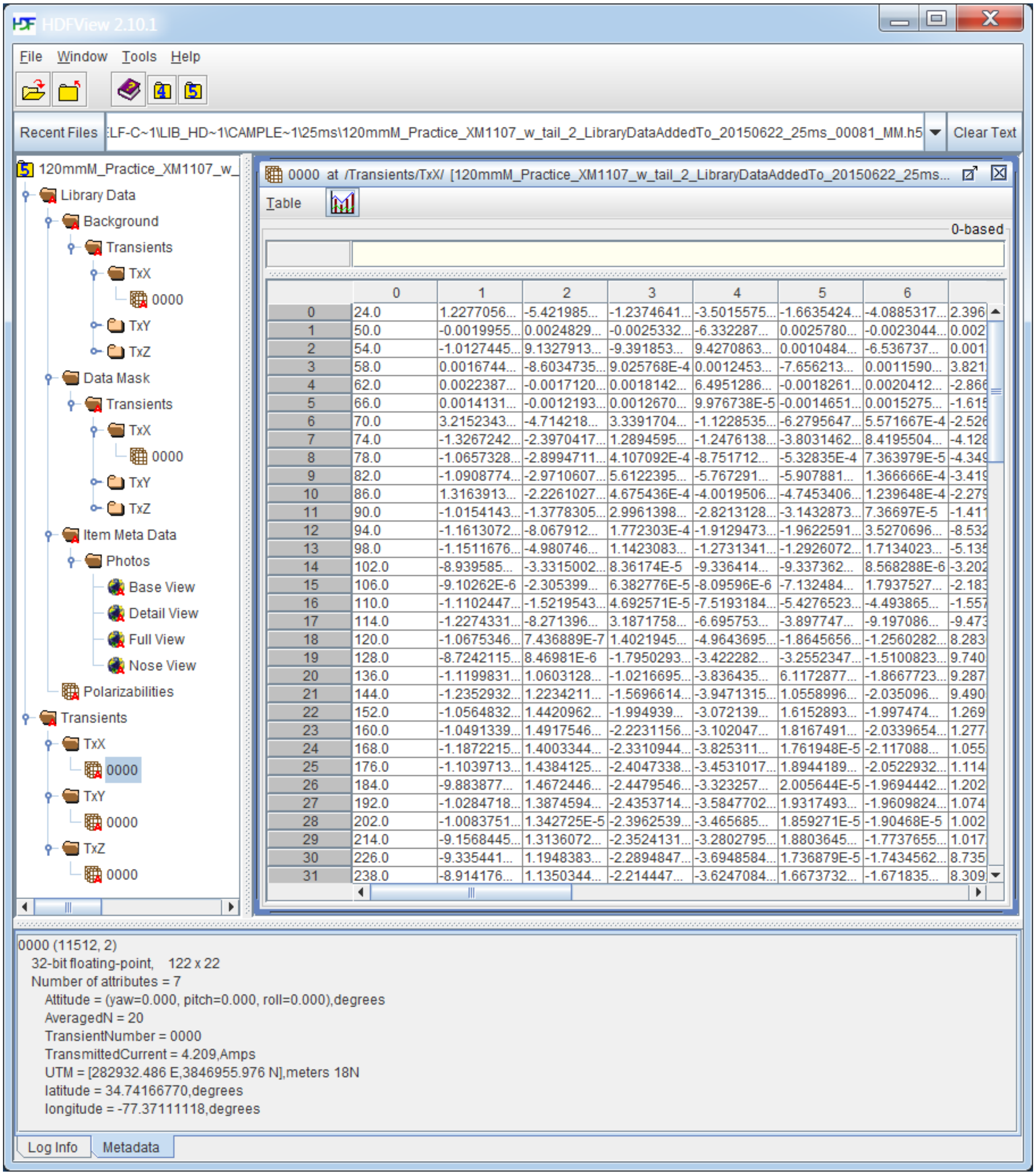

Figure 5-7 – The **TxX** sub-group dataset in the **Transients** group is shown in the main window. This represents the data in all the receiver channels – 21 (3 orthogonal coils x 7 cubes) in the case of the MM – when the X transmitter coil is firing. The associated attributes for the highlighted **0000** dataset presented in the Metadata window shows the dataset size – i.e. 122 rows (all the time gates for the 25 ms decay length setting) by 22 columns (the first column for the time gates, in microseconds, followed by the 21 receiver channel data) – followed by additional information about the transmitted current and measurement location. Normally, if GPS were used, this is where all the GPS-related data would appear.

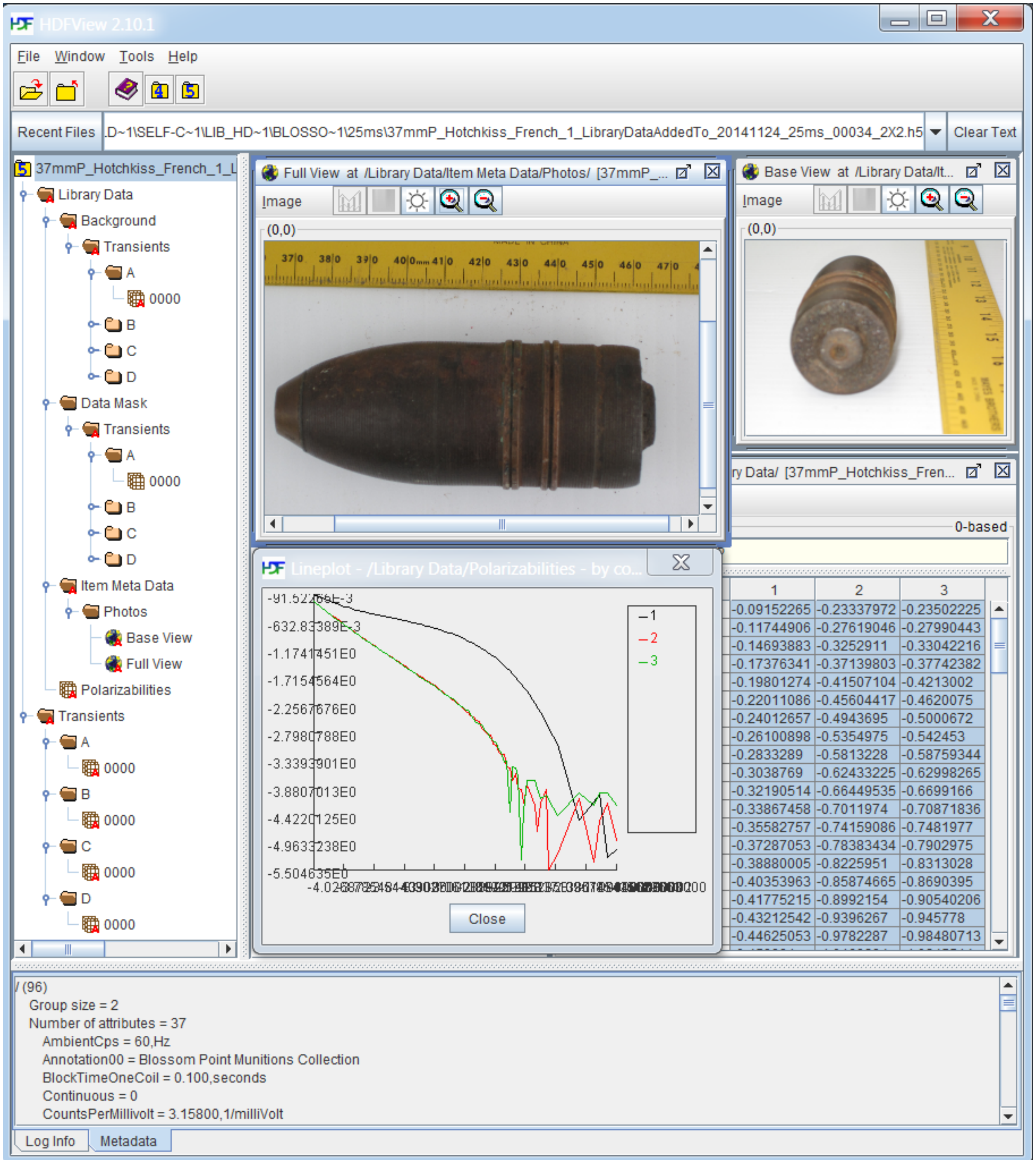

Figure 5-8 - An example of a library self-contained raw data HDF5 file for 2X2 data collected over a 37mm french Hotchkiss projectile at Blossom Point. In this case there are four sub-groups (**A-D**) within the **Transients** group each containing one dataset (**0000**) representing the data in all the receiver channels – 12 (3 orthogonal coils x 4 cubes) in the case of the 2X2 – when each of the A-D transmitter coils are firing.

6.0 CONCLUSION

The four objectives of the data collection stated in section 1.2 have been achieved:

1. Three classification libraries of polarizability curves at 3, 8 and 25 ms decay lengths have been created for common munitions;

2. Each munitions item entry to the libraries is accompanied by a standardized complete set of metadata;

3. A number of less common munitions have been added based on requests made from the larger MR community; and

4. An SOP (Appendix C) has been developed that will serve as a guideline for others wishing to collect high quality data in order to add more items to the libraries.

The final library product has been packaged in two different HDF5 formats: a library munitions item HDF5 file and a library self-contained raw data HDF5 file. The former format contains the munitions item metadata along with the inversion results for all the data collected over the particular munitions item, with a different HDF5 file created for each of the three libraries/decay lengths. The self-contained format is essentially the raw data file (i.e. the HDF5 data file that next generation Geometrics sensors are planning to dump) with the item meta data and inversion results – including the background data and a data mask that were both used with the raw data to give the inversion results – all embedded within the original file.

UX-Analyze is expected to import library self-contained format HDF5 files and use the raw data and background to generate both single- and multi-solver entries. Depending on the data being imported, the entries will be for a particular munitions item for one of the three libraries/decay lengths.

7.0 REFERENCES

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3. New Man-Portable Vector Time Domain Electromagnetic Induction Sensor and Physically Complete Processing Approaches for UXO Discrimination Under Realistic Field Conditions, SERDP Project MR-1443 Final Report, April 2012, http://www.serdp-estcp.org/content/download/15302/175070/file/MR-1443-FR.pdf

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5. http://www.geosoft.com/solutions/industry/government/government-sponsored-uxo-software

6. Portable Electromagnetic Induction Sensor with Integrated Positioning, SERDP Project MR-1712 Final Report, August 2013, http://www.serdp-estcp.org/content/download/20933/220064/file/MR-1712-FR.pdf

7. G&G Sciences, "Advanced Ordnance Locator for Standoff Detection & Classification of Surface and Buried UXO," G&G Sciences, Inc, Grand Junction, Final Report, December 2008.

8. Munitions Classification Library Update and Expansion Blossom Point Data Collection Report, ESTCP Project MR-201424 Technical Report, February 2015.

APPENDIX A. POINTS OF CONTACT

POINT OF CONTACT	ORGANIZATION	Phone e-mail	Role in Project
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Dr. Tom Bell	Leidos 4001 North Fairfax Dr. Arlington, VA 22203	703-312-6288 (O) thomas.h.bell@leidos.com	Data Analyst
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APPENDIX B. UNMEASURED DESIRED MUNITIONS

Item	Item	Item
Bomb, 6-lb, incendiary, M69	Projectile, 24mm Recoilless Rifle Round	Rocket, 5-inch, Practice, MK8
Bomb, Cooper (w/fins)	Projectile, 75mm, Japanese	Rocket, 5-inch, Zuni
Bomb, Cooper (w/o fins)	Projectile, 76mm, APT M339	Shot, 3-inch, AP-T, M79
Bomb, Fragmentation, 17-lb, Mk2	Projectile, 76mm, TPT M340	Signal, Flare, M27
Bomb, Fragmentation, 30-lb, Mk5	Projectile, 7-inch	Signal, Illumination, Slap Flare
Bomb, Practice, 100-lb, M38 (w/ fins)	Projectile, Mortar, 40mm, Illumination	Simulator MK 61
Bomb, Practice, Mk23	Projectile, Shrapnel, 3.8-inch	Simulator MK 64
Projectile, 1.1-inch, MKII	Projector, Levins	Spotting Charge, M1A1
Projectile, 105mm, Japanese	Rocket, 2.25-inch, SCAR (w/o motor)	Bomblet, 4-pound, incendiary, AN-M50
Projectile, 14.5mm	Rocket, 2.25-inch, SCAR, Motor	Bomblet, M114

APPENDIX C. SOP

STANDARD OPERATING PROCEDURE

Data Collection for Classification Library Updates

1 Purpose and Scope

The purpose of this Standard Operating Procedure (SOP) is to identify the means and methods to be employed when acquiring data using an advanced electromagnetic induction (EMI) sensor over one or more munitions items where the intent is to extract polarizabilities (βs) for addition to the Classification Libraries. The advanced EMI sensors refer to sensors such as the TEMTADS 2x2 (TEMTADS) or the MetalMapper (MM); while the Classification Libraries refer to the separate libraries needed for the different standard acquisition settings used during dynamic and cued operation of these sensors - i.e. the 2.78, 8.33 and 25 ms decay settings, which will henceforth be referred to, respectively, as the 3, 8 and 25 ms decay settings. The Classification Libraries are essential tools in support of the classification analyses efforts that are afforded by use of advanced EMI sensors.

2 Personnel, Equipment and Materials

2.1 Personnel and Qualifications

The following individuals will be involved in the data collection:

- Field Geophysicist

  Qualifications: Experience with operating the advanced EMI sensor to be used

  Responsibilities: Collecting data over the munitions item(s) and keeping a detailed activity log

- Quality Control (QC) Geophysicist

  Qualifications: Experience with processing and analyzing advanced EMI sensor data

  Responsibilities: Oversight of the data collection process with the aim of maintaining data integrity

- UXO Technician

  Qualifications: Certified/knowledgeable in identifying munitions items

  Responsibilities: Collecting the necessary metadata for the munitions item(s) in question and providing safety escort for the team

- Data Analyst

  Qualifications: Experience with processing and analyzing the advanced EMI sensor data

  Responsibilities: Detailed examination of the data with the ultimate goal of extracting high quality βs for the munitions item(s) to be included in one or more of the Classification Libraries

The roles of the QC Geophysicist and Data Analyst may be combined if the workload permits.

2.2 Equipment

The following is a list of required equipment:

- Advanced EMI sensor system – e.g. TEMTADS or MM
- Non-metallic test stand (to support the sensor)
- DAQ computer stand/table
- Calibration object (medium ISO schedule 80)
- 25' metric tape measure
- Digital camera
- Optional: Computer accessories – e.g. external display, keyboard, mouse, etc.

2.3 Materials

The following is a list of recommended materials:

- Wooden boards of various size and length
- Styrofoam sheets and/or blocks of various size and thickness
- Permanent markers
- Zip ties
- Electrical tape

3 Procedures and Guidelines

3.1 Equipment Setup

The goal here is for a cost-effective and straightforward setup that allows for efficient collection of high quality data over the munitions item(s) in question. Refer to **Figure 1** for pictures portraying a successful setup configuration when using the MM over a wide range of munitions item sizes.

A. **Assemble the test stand**

Important Considerations:

I. The test stand must be such that the height can be easily adjusted – this is especially important in indoor settings where attaining an optimal sensor height in relation to the floor, ceiling, and the presence of the largest target to be measured is necessary to avoid saturating the sensor response channels (refer to step **3.2**.D.ii. on how to determine if saturation is taking place and on how to fix the problem)

II. Whether the test stand is being assembled indoors or outdoors, care must be taken to account for all potential sources of interference

i. If another EMI sensor is operated simultaneously, maintain an offset distance between sensors of at least 100m (300ft)

ii. If indoors, keep lights and other AC electrical equipment (battery chargers, etc.) off while operating – i.e. at least those within a 10m (30ft) radial exclusion zone about the test stand

iii. All metallic objects within a 3m (10ft) exclusion zone must not be moved during measurement sequences starting and ending with background shots. Any tools and metallic objects that are expected to be used during data collection should be stored well outside this exclusion zone

Note: If any of the potential sources of interference listed above does take place during data collection, you will need to stop and recollect all measurements taken from the last background measurement onwards before proceeding

III. The test stand must be stable enough so that no movement can take place during sensor operation. Keep in mind that wind can be a source of movement

Note: If movement of the test stand does take place during data collection, you will need to stop, secure the stand, and recollect all measurements taken from the last background measurement onwards before proceeding

B. **Secure the sensor array on the test stand**

Note: If movement of the sensor array does take place during data collection, you will need to stop, secure the array more rigidly to the stand, and recollect all measurements taken from the last background measurement onwards before proceeding

C. **Assemble the DAQ computer stand**

Important Considerations:

I. Place computer stand as far away as cabling will safely and comfortably allow

II. If within the 3m (10ft) exclusion zone:
- DAQ computer location must remain securely fixed
- Chair used, if any, must be non-metallic

Note: If II. is violated in any way, you will need to stop and recollect all measurements taken from the last background measurement onwards before proceeding.

Figure 1 – Photographs showing varying aspects of a successful sensor test stand configuration. The plastic shelving is affordable, adjustable and widely available; the wooden boards serve well in providing a stable platform for the MM sensor; and the Styrofoam blocks are both light and strong enough to support a range of item sizes to be measured at various distances, thus ensuring efficiency while preserving versatility. In addition, the cabling and DAQ computer stand are secured and positioned in such a way as to minimize interference during the data collection process.

D. **Connect all cabling per manufacturers' documentation**

TEMTADS: *TEMTADS MP 2X2 Cart User's Guide, v2.00*, MTADS Program, US Naval Research laboratory, Chemistry Division, Washington, DC, May 2014
MM: *MetalMapper Manual, Preliminary Version*, Geometrics Inc., San Jose, CA, July 2011

E. **Secure cables and strain-relief**

This step is generally considered good practice since unsecured cables can:

- Be damaged, through straining
- Get disconnected, by getting unplugged
- Cause noise in the data, by moving during data collection activities.

3.2 Initial System Check

The goal here is to verify that the sensor operates correctly and is free of undesired interferences.

A. **Turn on the system**

B. **Set up the different acquisition parameter settings**

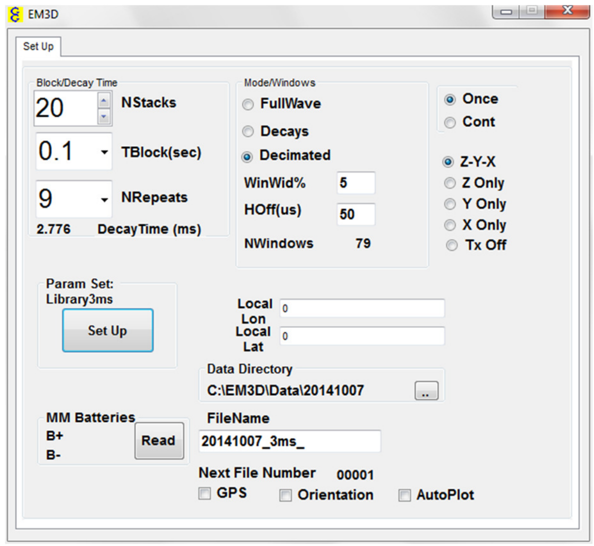
The procedures to save different sensor acquisition settings are straightforward and can be found in the manufacturers' documentation. This step is particularly important if the intent is to collect data over more than a couple of items at all three decay settings since the operation of going from one set of sensor settings to a different one will be reduced to a single mouse click on a drop down list. **Figure 2** shows the MM EM3DAcquire v6 screens that are relevant to the set up process.

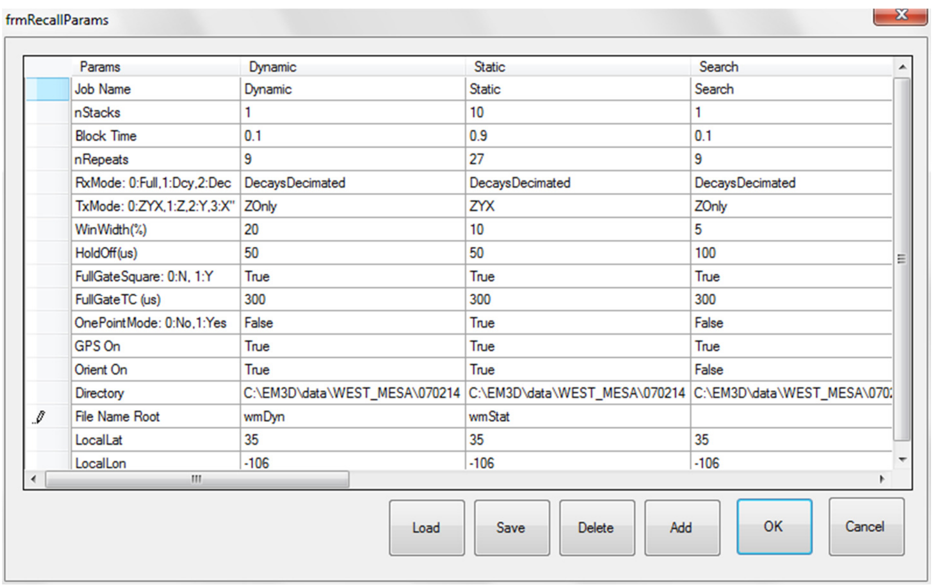
C. **Display all essential plots for QC purposes**

The ability to view the data upon collection allows for a much better chance of catching sensor malfunctions or other interferences in the data as they occur. **Figure 3** shows the MM EM3DPlot screen that allows one to define the data plot windows along with the recommended layout for efficient viewing. The plots are: (left window) the Tx currents for each Tx coil with all curves over-plotted; (top right window) the Z,Y,X channel responses from left to right, respectively, for each Rx cube – with all Rx curves over-plotted – when the TxZ coil fires; (middle right window) same plot configuration as those just described but for when the TxY coil fires; and (bottom right window) ditto for when the TxX coil fires. The decay data shown in the rightmost windows are collectively referred to as the TxRx pair data.

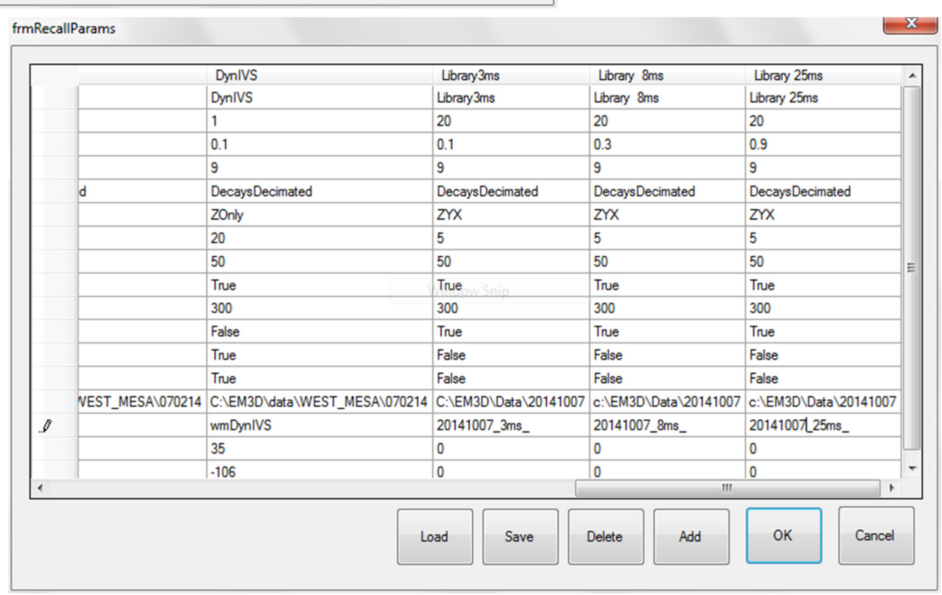
D. **Verify that the sensor operates correctly and is free of undesired interferences**

I. Acquire a static measurement using the acquisition parameter settings resulting in the 3 ms decay with the recommended effective stacking (NStacks*NRepeats) of at least 180 and examine the following (the 3ms decay is chosen here to expedite matters, but any of the three decays maybe used):





Params	Dynamic	Static	Search
Job Name	Dynamic	Static	Search
nStacks	1	10	1
Block Time	0.1	0.9	0.1
nRepeats	9	27	9
RxMode: 0:Full,1:Dcy,2:Dec	DecaysDecimated	DecaysDecimated	DecaysDecimated
TxMode: 0:ZYX,1:Z,2:Y,3:X"	ZOnly	ZYX	ZOnly
WinWidth(%)	20	10	5
HoldOff(us)	50	50	100
FullGateSquare: 0:N, 1:Y	True	True	True
FullGateTC (us)	300	300	300
OnePointMode: 0:No,1:Yes	False	True	False
GPS On	True	True	True
Orient On	True	True	False
Directory	C:\EM3D\data\WEST_MESA\070214	C:\EM3D\data\WEST_MESA\070214	C:\EM3D\data\WEST_MESA\0702
File Name Root	wmDyn	wmStat	
LocalLat	35	35	35
LocalLon	-106	-106	-106



	DynIVS	Library3ms	Library 8ms	Library 25ms
	DynIVS	Library3ms	Library 8ms	Library 25ms
	1	20	20	20
	0.1	0.1	0.3	0.9
	9	9	9	9
d	DecaysDecimated	DecaysDecimated	DecaysDecimated	DecaysDecimated
	ZOnly	ZYX	ZYX	ZYX
	20	5	5	5
	50	50	50	50
	True	True	True	True
	300	300	300	300
	False	True	True	True
	True	False	False	False
	True	False	False	False
VEST_MESA\070214	C:\EM3D\data\WEST_MESA\070214	C:\EM3D\Data\20141007	c:\EM3D\Data\20141007	c:\EM3D\Data\20141007
	wmDynIVS	20141007_3ms_	20141007_8ms_	20141007_25ms_
	35	0	0	0
	-106	0	0	0

Figure 2 - The EM3DAcquire screens that are relevant to the acquisition parameters set up process for the MM are shown here. The top GUI allows one to set all the parameter values and upon clicking on the 'Set Up' button launches another GUI represented by the middle screen. The lower screen is the same GUI, but now the hidden rightmost columns are revealed by use of the slider. In this case, the last three columns reveal the three different parameter settings saved under the names of Libray_3ms, Library_8ms and Library_25ms.

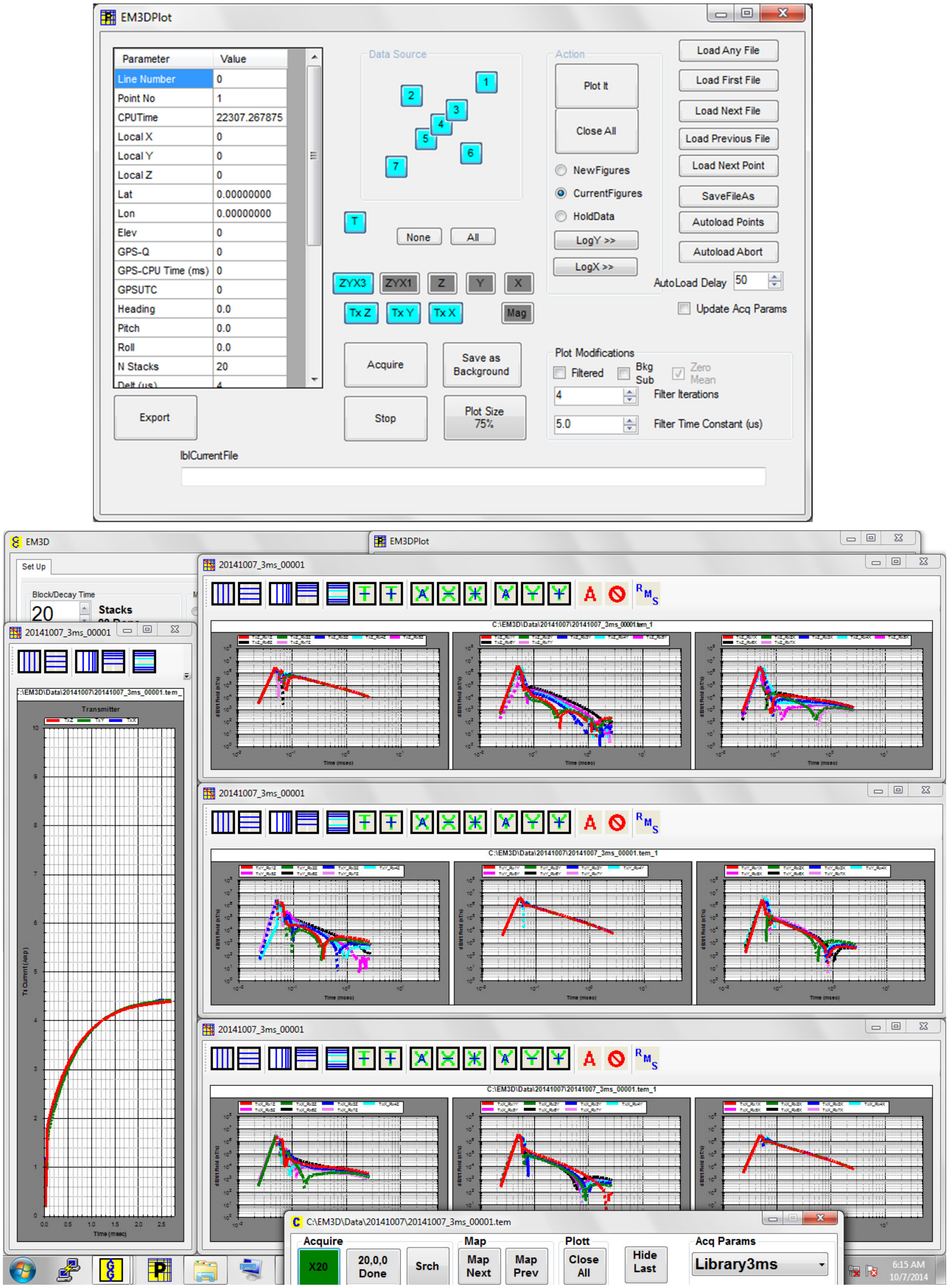


Figure 3 – The EM3DPlot screen that is relevant to setting up the data plot windows for the MM is shown at the top. This GUI allows one to specify the data plot windows to launch by clicking on the buttons (blue) before hitting the 'Plot it' button. Data must be loaded before the plot windows can launch and be arranged for easy viewing as shown above. Once open, the plot windows will continually replenish themselves with the most recently acquired data. The EM3DAcquire window at the very bottom allows for the efficient selection of acquisition parameters via a dropdown list before the 'Acquire' button (green) is hit.

i. **Tx Currents**

All Tx currents should be in the range of within ~80% of being fully charged, i.e. for

TEMTADS:	5.5 – 6.8 Amps
MM:	3.6 – 4.5 Amps

ii. **TxRx Pair Data**

Scan all TxRx pair data decay plots for any abnormal signs, such as flattened decays, step discontinuities, extended growing trends towards the later time gates, and missing (i.e. 0 or NaN) data

Note: If there are signs of flattening at rail (i.e. maximum/positive and minimum/negative) values at the early time gates, this is an indication of saturation taking place and suggests that the sensor location may need to be changed. Increasing the sensor distance from obvious metallic structures – such as raising the sensor on the test stand away from a steel reinforced floor – will likely help as long as there is space to move without being influenced by other surrounding metallic structures – such as a metal roof, in this case. If there are no attainable "sweet spots" at a particular location (i.e. where all TxRx pair channels do not show signs of saturation), then the location must be changed entirely – e.g. from indoors to outdoors. If there is a "sweet spot" for the sensor, remember that this must also accommodate the item(s) to be measured without going into saturation and without having to place the item(s) too close to the steel reinforced floor. A good test is to insert the largest item in the vertical orientation under the center of the sensor. In this case, the center RxZ channel for the MM will likely be the first to saturate (see **Figure 4** for an example of saturation in the Rx4Z channel taking place). For the TEMTADS, all 4 RxZ channels should saturate simultaneously. By focusing on these channels, the sensor location can further be tweaked to allow for an acceptable range of measurement positions for the item where no saturation will take place and enough of a stand off from the floor exists (~L/2) to rule out possible mutual interaction effects. If an acceptable range of measurement positions is not attainable, then the setup location must be changed entirely, at least when measuring the larger items in question.

Note: If the Tx current values and the TxRx pair data appear normal, then proceed; otherwise diagnose or seek support from the manufacturer to resolve any outstanding issues before proceeding.

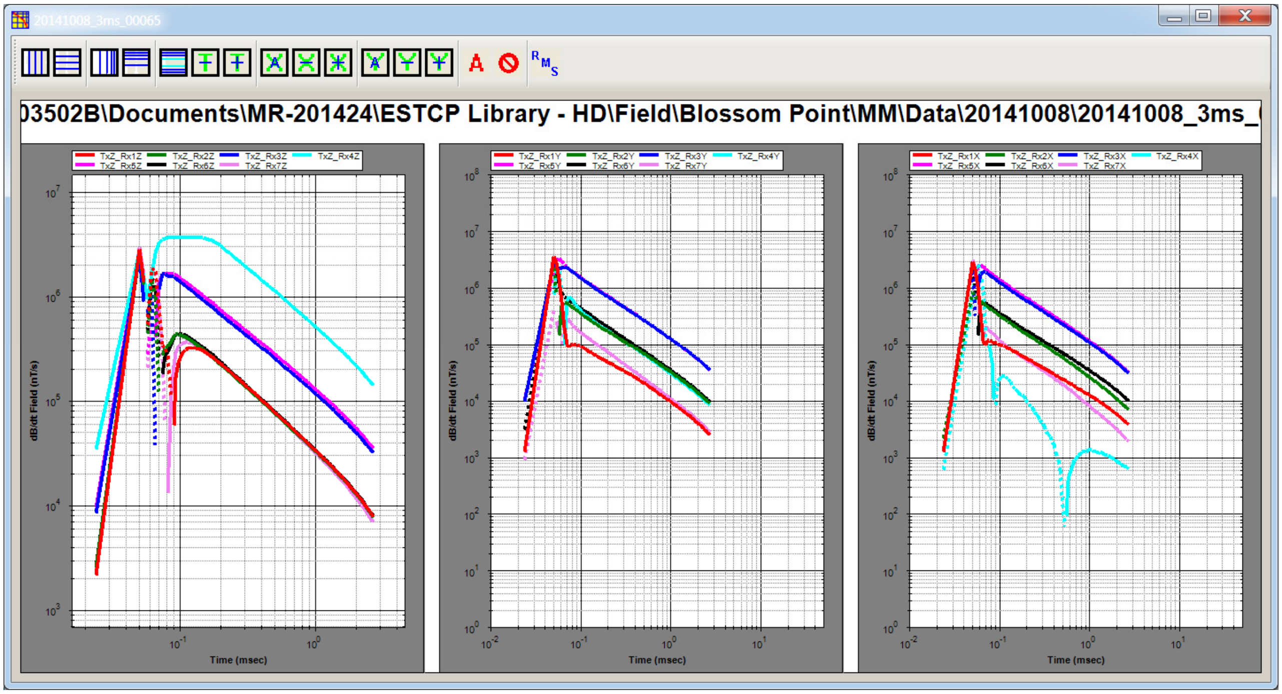


Figure 4 – The MM TxZ_Rx4Z decay (leftmost cyan curve) showing tell-tale signs of saturation where it flattens out in early time at a maximum of just under $4x10^6$ nT/s. Since Rx4 is the center Rx cube in the MM, this is suggestive of a metal source being too close to the center of the array. A remedy would be to increase the distance between the MM and the metal source until the flattening disappears and the decay beyond $8x10^{-2}$ msec only shows signs of decreasing.

II. Differenced Background Data

Acquire a couple of sequential static measurements using the 8 ms decay time parameter settings and designate one of them as the background (using the 'Save as Background' button as seen in **Figure 3**). For the other, examine the following for all the background-subtracted TxRx channel data (obtained by activating the 'Bkg Sub' checkbox in **Figure 3**):

i. Slope of decay

The general decay of the differenced background data for all channels should follow a $1/\sqrt{t}$ trend – a straight line on a log-log plot with a negative rise to run value of 1:2. This means that the trend line drops one large division for every two large divisions in time. This is clearest when looking at the decay portion beyond 10^{-1} msec in the top three plots of **Figure 5**.

It should be noted that if enough time elapses between the two backgrounds that are differenced, then the actual changes in background will start to creep into the data starting with the monostatic channels. This is especially relevant when collecting data in high gradient environments such as an indoor setting. In **Figure 5**, the bottom three plots

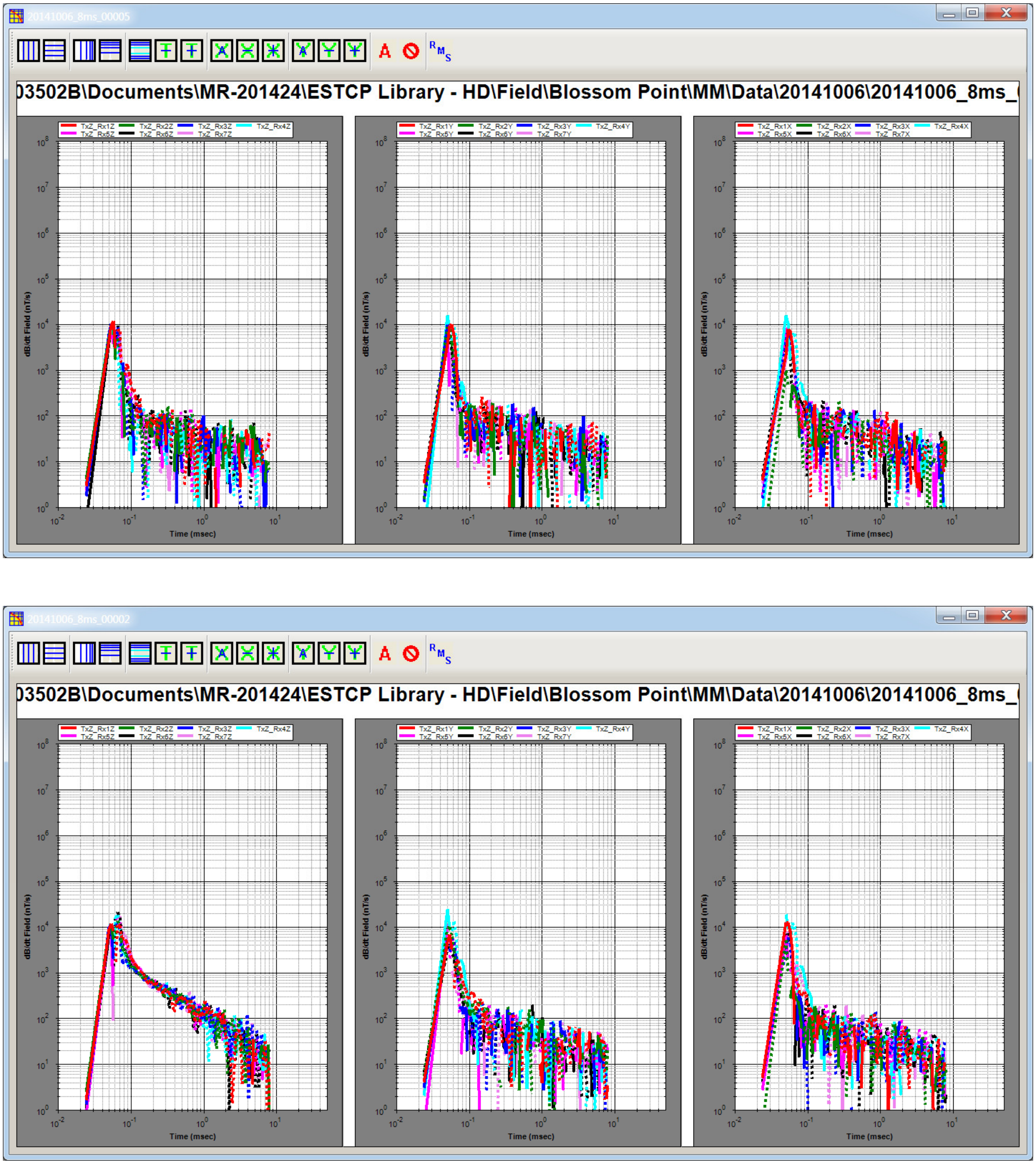


Figure 5 – Differenced data for sequential background shots separated by about 2 minutes (top three plots) versus about 14 minutes (bottom three plots). The general decay of the differenced background data for all channels should follow the expected sensor noise trend of $1/\sqrt{t}$. This is a straight line on a log-log plot with a negative rise to run value of 1:2, or a drop in one large division for every two large divisions in time. The top three plots show this behavior very clearly for the decay portion beyond 10^{-1} msec. When too much time elapses between backgrounds that are differenced, actual background changes will start to creep in changing the slope. This starts with the monostatic channels, as seen here by the leftmost lower plot.

are differenced data for sequential background shots taken 14 minutes apart, instead of just 2 minutes apart for the top set of plots. As is clear in this example, the slope for the differenced monostatic decays changes due to the influence of the interim varying background. It is therefore important to allow the smallest amount of time to lapse between backgrounds collected for this exercise.

ii. **Maximum acceptable amplitude**

All TxRx trace amplitudes at $2x10^{-1}$ msec should read:

- TEMTADS: $<10^{-1}$ mV/A
- MM: $<3x10^{2}$ nT/s

While the interfaces for both the TEMTADS and MM systems are expected to be standardized in the future, they currently display the TxRx pair data in different units. To go from mV/A to nT/s, the conversion factor is $1000*I_{Tx}$/(effective area of the Rx coil)

Note: If both i. and ii. are violated, this is suggestive of a likely source of electromagnetic interference. The background differenced data must be recollected with all possible local sources of interference – i.e. any lights, especially fluorescent lights, and other AC electrical systems – powered down. **Figure 6**, for example, shows the effect of fluorescent lights. If the issue persists, diagnose further or seek support from the manufacturer to resolve any outstanding issues before proceeding.

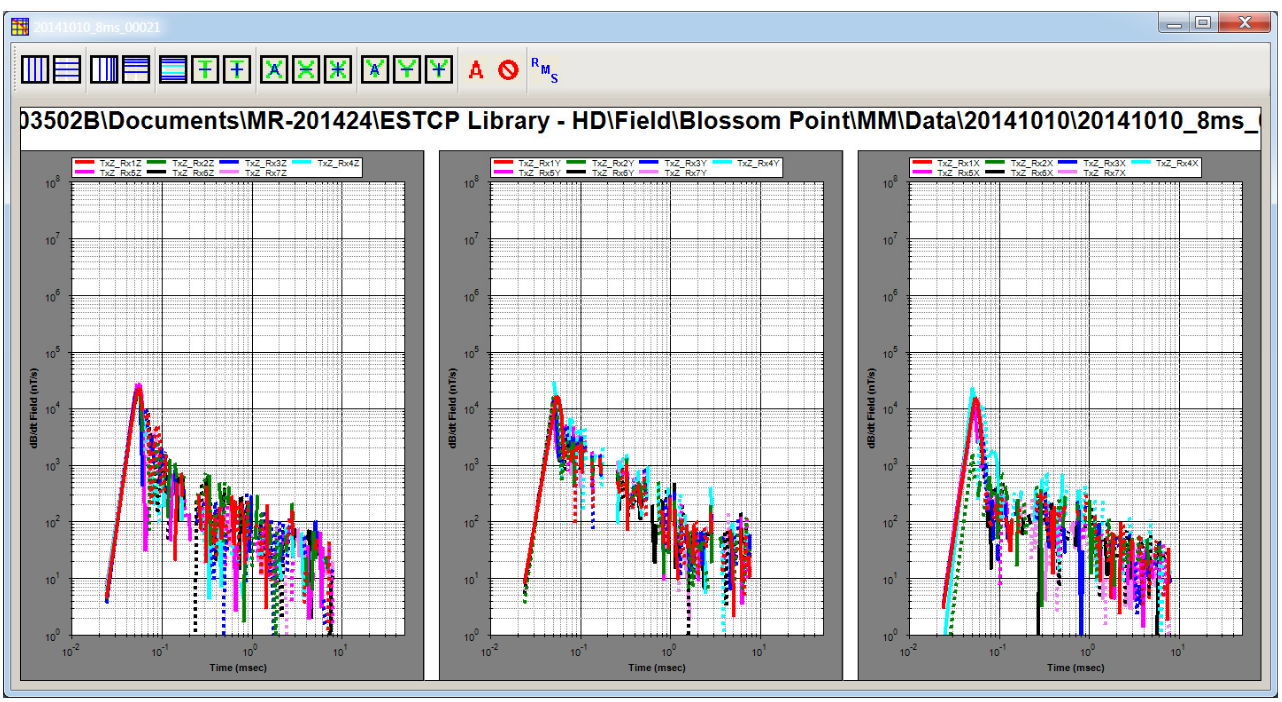


Figure 6 - Differenced background data showing the effects of overhead fluorescent lights. In this case, both the slope and amplitude tests fail.

3.3 System Calibration and Repeatability

The goal here is to verify that the sensor:

1. Responds predictably to a standard object (calibration); and
2. Continues to do so throughout the data collection (repeatability).

The standard object of choice is the medium schedule 80 ISO (specifically, a black, welded steel, Schedule 80, straight pipe nipple, threaded on both ends, obtained at http://www.mcmaster.com/ as part number is 4550K292). The reasons are that these are widely available; are manageable to handle; provide for healthy responses; and demonstrate reproducible βs at all three decays over a number of different samples.

In order to have meaningful measures of success for both the calibration and repeatability stages that are based directly on the TxRx pair data, accurate and consistent positioning of the ISO is a critical requirement. This demands either specialized apparatuses or great time and pains to attain the necessary positioning to achieve success. Thus, for generality as well as expediency purposes, measures of success will instead be based on the βs extracted from the collected data. In the case of the TEMTADS, data will be collected by placing the ISO under the center of the array, while for the MM, an additional two off-center locations are recommended to ensure that problems with the outermost Rx cubes are more readily detected (refer to **Figure 7** for definitions of the recommended off-center locations).

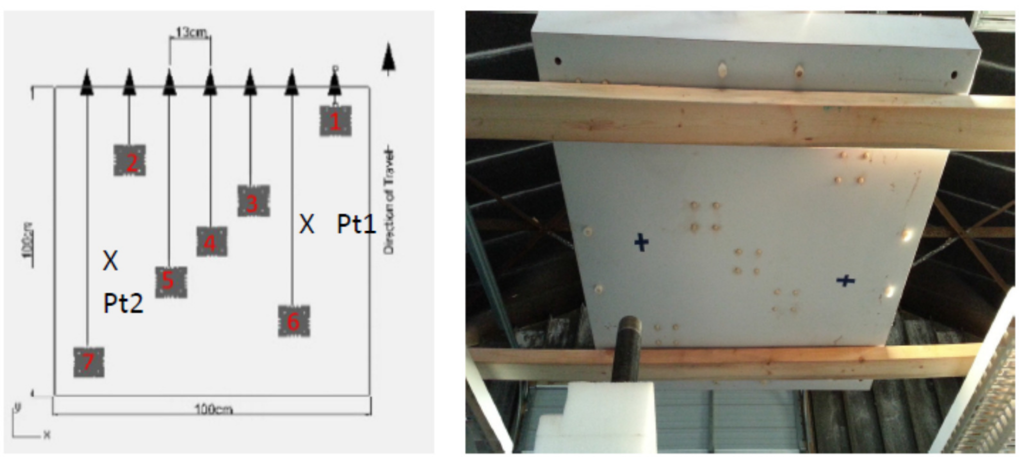


Figure 7 - The off-center locations for the MM defined as: Pt1 – approximately equidistant to Rx1, 4 & 6; Pt2 – approximately equidistant to Rx2, 4 & 7. The top of both panels above represent the front of the MM, but the schematic panel is a view from the top. This means that the ISO in the photo is under Pt1.

For the calibration phase, the expectation is that the βs for the different decay data will be extracted with a fit coherence > 0.99 and match to a high degree with the existing medium schedule 80 ISO entries in the respective libraries. There are many measures for a good match, but the following should be true: βs must match 'to the eye' in both shape and amplitude; and the UX-Analyze 3-β match metric must be well above 0.9.

Repeatability of the system over the duration of the data collection period will be verified by collecting data over the ISO each time the sensor is restarted for data collection activities. These episodes will be referred to as the daily QC data collection (see step **3.5**B.). For the repeatability measure of success, the βs must be extracted from each daily QC data collection with a fit coherence > 0.99 and must match extremely well with the initial set of βs extracted during the calibration phase. In this case, the UX-Analyze 3-β match metric must be well above 0.95.

A. **Collect the standard object data**
    I. For decay settings of interest, collect:
        i. Background
        ii. **TEMTADS:** Vertically-oriented ISO centered under the array at a depth of 32cm
        MM: Vertically-oriented ISO centered under the array at a depth of 32cm and also under each of the off-center points (Pt1 and Pt2 defined in **Figure 7**) at the same depth
        Note: The depth is defined as the distance from the bottom of the sensor housing to the center of the item

B. **Transfer and store the data**
    I. Place all data in .zip files or other such archives prior to transfer for efficiency and to preserve date/time metadata of files
    II. Copy to long term secure storage system

C. **Consult with the data analyst**
    I. Obtain verification of the integrity of the system (i.e. that Tx current values and all TxRx channel signal and noise levels are normal).
    II. Obtain verification that the system is calibrated by ensuring that the βs for the ISO are extracted with a fit coherence > 0.99 and are consistent with existing library entries (i.e. that a UX-Analyze 3-β match metric well above 0.9 is attained, for example). In addition, any off-center βs should be consistent with βs extracted from the data collected under the center of the array (with a UX-Analyze 3-β match metric well above 0.95, in this case).
    III. Make any necessary changes based on the findings

3.4 Before Data Collection

A. **Check batteries**

If batteries are below 90% fully charged, replace batteries with fully charged ones and place low ones on charge

B. **Create a 3m (10ft) radial area exclusion zone around the test stand**

Clear all metallic objects that may be moved during the data collection period from the exclusion zone. Also, refrain from entering the exclusion zone while the sensor is acquiring data.

C. **Ensure that all items to be measured have identifiers**

For each item to be characterized, ensure that each item has a unique, non-removable identification marking (e.g. stamped serial number). If no such marking exists, apply a temporary identifier number and collect a photograph of the item, displaying the marking

3.5 Daily Startup Activities

A. **Connect batteries to the system and turn the system on**

B. **Collect the daily QC data**

This follows the same steps outlined in step **3.3**A. In addition:

I. Verify that the system is operating as expected
   i. Tx currents are in the expected range (step **3.2**D.I.i)
   ii. No anomalous TxRx traces exist (i.e. flattened lines, step discontinuities, etc)
II. Send data to analyst
   i. All βs must be extracted with a fit coherence > 0.99
   ii. All βs must match previously extracted βs (with a UX-Analyze 3-β match metric well above 0.95, for example)

3.6 Data Collection Activities

For each item:

A. **Photograph (to be included as metadata accompanying the βs)***

I. Place the item on a solid white color background with the long axis parallel to a clearly visible ruler; lighting should be such that shadows are minimized

II. Photograph

III. Repeat for any additional orientations necessary to capture the complete state of the item Examples:

   i. Base view – to document if the base plate is present, or if the item is filled or empty

   ii. Nose view – to show if the fuze is missing, or if non-symmetry exists

   iii. Other views – to record dents or other damage

   iv. Item markings, if still visible

Figure 8 - Example photographs for a BDU-33 25-lb practice bomb showing (from left to right) a full view; a base view; and a nose view.

B. **Identify (based on markings and other identifiers)***

I. Fill in all cells of **Table 1** in Appendix A (The UXO tech must approve all entries before going on to the next step)

II. Forward the completed item metadata to the data analyst for inclusion with the extracted βs in the classification libraries

C. **Collect sensor data**

I. Place the item at one of the ***required three orientations (i.e. Horizontal; Vertical, nose down; or Vertical, nose up)*** at a depth equivalent to the largest dimension of the item (L) and check if saturation of any TxRx pair channel data occurs (refer to step **3.2**D.ii. on how to determine if saturation is taking place)

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* Activity may be conducted asynchronously for efficiency, as long as each item has a clear identifier as discussed in step **3.4**C.

If saturation occurs, increase the depth by the suggested increments until saturation in all channels has been eliminated:

i. ***Small*** (i.e. caliber < 50mm)**: *1cm increments***
ii. ***Medium*** (i.e. 50mm < caliber < 100mm)**: *2.5cm increments***
iii. ***Large*** (i.e. caliber > 100mm)**: *5cm increments***

Note: The above rules of thumb are recommendations only and should not replace common sense. The goal of this exercise is to move the item far enough away from the sensor to prevent saturation, without sacrificing signal strength by moving it further than necessary. If the signal is weak and it appears that more signal strength could be gained by moving it closer (without saturation reoccurring), than do so provided depth > L.
Note: Large aspect ratio items (i.e. where L/OD > 6) will at times, for particular orientations, present weak signal strengths at L. In those cases, the starting depth should be moved closer between L/4 and L/2 to obtain a healthy signal.

II. For ***all decay settings*** of interest, collect:
  i. Background
  ii. Item, as oriented and at the depth determined in step I.

III. Repeat steps I. and II. for remaining orientations

Note: The Backgrounds in step II. may not need to be collected each time. This will depend on how much time has elapsed since the last backgrounds were collected. It is recommended that backgrounds (for all decay settings of interest) be taken at 20 minute intervals, never to exceed 30 minutes

Note: The horizontal item orientation relative to the array should also be recorded. For example, H-NPt1 for the MM might signify that the item is horizontal and oriented across track with the nose pointing towards the Pt1 side.

IV. Repeat step II. for a second depth for all three orientations.

Rough guidelines for selecting the second depths are:
  i. ***Small****:* add L/2 to the first depth
  ii. ***Medium:*** add between L/3 and L/2 to the first depth
  iii. ***Large:*** add between L/4 and L/2 to the first depth

Note: The goal here is to move the item a distance of L/2 further from the sensor but still maintain sufficient signal strength to be able to extract secondary βs that can be reliably compared to the ones extracted at the shallower depth. For those items with large aspect ratios, this may be a problem and so a shallower second depth is needed.

Note: If an extended interruption in the data collection occurs before background data can be collected, always resume by recollecting all measurements taken from the last background measurement onwards before proceeding. The goal is to always have the data sandwiched by two backgrounds collected less than 30 minutes apart.

3.7 Daily Shutdown Activities

A. **Transfer and store the data**
   I. Include field notes and photographs with the sensor data files
   II. Place all data in .zip files or other such archives prior to transfer for efficiency and to preserve date/time metadata of files
   III. Copy to long term secure storage system

B. **Power down and secure the system**

C. **Place all batteries on charge**

4 Quality Control

Practical considerations limit the real-time QC of the data acquisition activities to mostly qualitative assessments. A complete quantitative assessment will be performed post-collection by the data analyst. The full set of measurement quality objectives (MQOs) are as follows:

	MQO	Metric	Success Criteria
	For each munitions item		
1	Were the complete metadata collected?	Table 1, Appendix A; photograph(s)	Table 1 completed; photograph(s) taken
2	Were data collected at all decays of interest?	Intention coming into the data collection	All targeted libraries addressed
3	Were all required data collected?	Step **3.6**C of this SOP	*At a minimum,* 3 required orientations at two depths
	For each data set collected for extraction of βs		
4	Was inversion successful?	Fit coherence (with sanity check of position & orientation parameters)	Fit coherence > 0.98* (with X,Y,Z to within +/- 15 cm** and Tilt & Azimuth to within +/- 30^{o}***)
	Validation of ISO βs extracted		
5	Do extracted βs agree with existing Classification Libraries entries?	3-β match to βs in existing Classification Libraries	> 0.9
	Daily QC data		
6	Are extracted βs for the ISO as expected?	3-β match to initial βs extracted	> 0.95

* Fit coherence > 0.90 may be more appropriate for large aspect ratio items

** For larger items in the vertical orientation Z to within +/- 30 cm

*** Tilt & Azimuth bounds may sometimes be meaningless for large and/or composite items, especially for the 3 ms decay data

The data will not be used to update the Classification Libraries until these MQOs are met or until the project team agrees on modifications to these MQOs.

Appendix A

Table 1 - Required munitions descriptive information to accompany photographs and βs, with an example entry for the BDU-33 25-lb practice bomb represented in **Figure 8**. Note that the Qualifier/Pedigree field is based on Andy Schwartz's definition as stated below the table.

Name		25-lb Bomb	
Mark/Mod		MK76	
Dimensions (mm)	**OD**	102	
	Length	635	
Common Name		BDU-33 Practice Bomb	
Class Category		Bomb	
Fins?		Y	
Fuzed?		N	
Spotting Charge?		N	
Rotating Band?		N	
Appearance/Condition		Fired/Bent	
Qualifier/Pedigree*		B	
Photo(s)		2068,2069,2070	
Serial Number		NRL PB-1	
Comments			

***The following gradations are used:**

A. **Fully described**
B. **Known Mark/Mod, not fully described**
C. **Only outer diameter(OD) or common nomenclature is known**
D. **TOI shape confirmed but no other nomenclature available or is not trusted**

Attachment 1

SOP Startup QC Checklist

This checklist is to be completed by the QC Geophysicist before moving on to the item data collection activities.

QC Step	QC Process	Yes/No	Initials of QC Geophysicist
1. Equipment Setup	Have all steps been followed?		
2.Initial System Check	Were all steps successfully completed?		
3.System Calibration	Have all steps been followed and has the data analyst confirmed the expected operation of the system based on MQOs 4 & 5?		
4. Before Data Collection	Have all steps been followed?		

SOP Data Collection QC Checklist

This checklist is to be completed by the QC Geophysicist for each daily data collection.

QC Step	QC Process	Yes/No	Initials of QC Geophysicist
5.Daily Startup Activities	Were all steps successfully completed and has the data analyst confirmed the expected operation of the system based on MQOs 4 & 6?		
6.Data Collection Activities	Have all steps been followed?		
7.Daily Shutdown Activities	Have all steps been followed?		

SOP Successful Completion QC Checklist for each Item

This checklist is to be completed by the QC Geophysicist (with input from the Data Analyst) before ending the data collection activities.

QC Step	QC Process	Yes/No	Initials of QC Geophysicist
1. MQOs 1-3	Have all checklist items been addressed?		
2.Additional Configurations?	Has the data analyst recommended more measurements based on great variations observed in the extracted βs?		
3. MQO 4	Were the inversions successful based on the fit coherences and position/orientation parameters?		